AN INSTITUTIONAL ANALYSIS OF THE ARCHITECTURAL PROFESSION AND PASSIVE SOLAR ENERGY: THE DISCOVERY OF HIDDEN BARRIERS

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SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE
DEGREES OF

MASTER OF ARCHITECTURE IN ADVANCED STUDIES

AND

MASTER OF CITY PLANNING

AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY
MAY 1979

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Submitted to the Department of Architecture and to the Department of Urban Studies and Planning on May 21, 1979, in partial fulfillment of the requirements for the degrees of

Master of Architecture in Advanced Studies
and
Master of City Planning

ABSTRACT

This study is an examination of the institutional arena within which the architectural profession reacts with the rest of society, and a search for the reason why a technology as economically and functionally successful as 'passive' solar energy has not yet been integrated into the pattern of society.

Much of the support for solar energy has made use of the same approaches for both 'active' and 'passive'. 'Active', however, is basically an engineering solution which can be incorporated into the routine of design with relatively little impact on the role of the architect. It is essentially a replacement technology, where one mechanical system is used in place of another.

'Passive', on the other hand, is so integral to architectural design that it cannot be left to a professional expert whose field is external to architecture. Rather than being a replacement technology, it implies a radical restructuring of the responsibility, and therefore of the role, of the architect, because it calls for a technical command which is foreign to many.

An analysis of the profession as an institution which contributes to the meaning of the cultural environment suggests that the acceptance of this responsibility by the architect has a profound impact on the qualifications needed to practice, on the 'image' of the architect, and on the place of the architect in society.

Because these impacts are so strong in the case of 'passive', and so minimal in the case of 'active', it is unlikely that any program directed at the removal of barriers to active will have the same, or indeed any, effect on 'passive.

Certain changes in the approaches of existing programs will help in the restructuring of the profession needed before energy conscious design techniques can be integrated again into the the routine of the architectural profession, contributing both to the place of the profession in our culture, and to a lessening of our cultural dependence on 'hard' energy solutions to technological problems.

Thesis Supervisor: Thomas E. Nutt-Powell,
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DEDICATION

For those who mean the most. For my sisters, Patricia and Frances Furlong; for my friends, Ken Kiernan, Isabel Paul, Alan Chalmers, Michael Sheehan, and Steven Gould; and, of course, for my mother, Madge.

How do you thank someone like Tom Nutt-Powell? It wouldn't have been possible without his advice and friendship. Nor would it have been half the fun. For which I also have to thank:

Anne Simunovic

Beth Frey

Bonnie Nutt-Powell

Cecca Le Roux

Christine Cousineau

Deborah Poodry

Glynton Le Roux

Gordon King

and

Irene Lee.

PREFACE

There is an undeniable concern about the problems which attend continued reliance on non-renewable energy sources, a concern which has recently been accentuated by the impact of political changes in the Middle East, and by events which have made the nuclear option less attractive to many Americans. For a number of years the use of solar energy as an alternative source for heating buildings has become more and more attractive, judging by the increasing number of 'solar' homes one reads about and sees built. To most people, however, 'solar' means 'active' solar energy, in spite of the fact that 'passive' can be shown to be equally effective, to have a considerably shorter pay-back period, and to be so integral to the design of a building that it has minimal impact on form and life-style.

Yet, in spite of all these apparent advantages, 'passive' solar energy is not gaining rapid acceptance. This study is concerned with identifying, and suggesting ways of overcoming, barriers which prevent 'passive', specifically, from being integrated into the routine of the building industry.

This industry, in one form or another, opposed the introduction of a multitude of innovations, a few recent examples being poly-vinyl chloride (pvc) pipe, copper plated tubing, the mobile home, and the whole concept of industrialized housing. The opposition has been manifest through regulation, finance, production, and political institutions. Yet, though each of these has contributed to the slow rate at which 'passive' solar energy has been accepted, they are not barriers unique to 'passive'.

If one thinks of the building industry as a pipeline flowing from design, through construction, to inhabitation, and if one moves back along the pipeline (considering both 'active' and 'passive solar technologies) the barriers which come to mind apply to each. This common set of barriers is encountered until one has tracked back almost to the beginning, to the responsibility of the professional designer. It is at this point that it appears that there is a unique, and what I call 'hidden' barrier, the nature and practice of contemporary design.

The process of innovation acceptance is dependent on an understanding of what the innovation means, or what its function is. This attribution of meaning and function can take place only when those who are supposed to be capable of doing what is necessary to implement the change are really capable of, and disposed to, doing it.

The general attitude that solar energy means 'active' systems with flat plate collectors and underground storage suggests that the concept of 'passive' has not been carried very far by those who are supposed to be responsible for, and capable of, doing 'passive' solar energy.

Because 'passive' is a solution which is integral to the process of architectural design, the responsibility for doing belongs to the architectural profession. It cannot be relinquished to any other profession without the architect relinquishing his responsibility for design. This was not the case with 'active' solar energy, which is readily routinizable by the mechanical engineer without altering in any way the responsibility of the architect. Because it appears that the 'hidden' barrier to the acceptance of 'passive' solar energy by the building industry lies in the nature and practice of architectural design, the major task of this study is to discover why routinization of this technology has found opposition among architects, an opposition which is almost subliminal, and how this opposition might be overcome.

Chapter 1 presents a theoretical framework for use in understanding the universe within which the architectural profession is defined to its participants and observers. Organizational theory is explored, and some conflicts between theoreticians resolved, to produce an internally consistent structure for the general analysis of institutions which follows.

Chapter 2 builds on the framework of organizational theory, abstracting those aspects of interaction among participants which make for institutional, or aggregated, contributions to the meaning structures of society. Because we tend to define ourselves in terms of the roles we are expected to play, and by the actions which are correct for those roles, an approach for understanding role definition is presented. A discussion of the nature of change (or innovation adoption) is offered in this context.

Using this analytical framework, Chapter 3 outlines the role of the architectural designer in terms of the salient aspects of design method, the nature of architectural practice, how 'passive' design is on one hand part of this tradition, and yet how it necessitates a redefinition of the currently perceived role of the architect.

In Chapter 4 an example of the incorporation of the constraints of 'passive' solar energy into what would have been a routine design without it is presented. To show the impact of the 'passive' constraint on the architect's perception of what actions can be expected from a designer, the gap between what is acceptable in routine design and what is essential for 'passive' design is described.

In the final chapter certain activities which can facilitate routinization of 'passive' solar energy techniques, by addressing the hidden barriers found in the design profession, are presented. Drawing on the theoretical framework presented in the first two chapters, these activities are evaluated to determine their possible success as deliberate intervention strategies to accelerate innovation acceptance.

CHAPTER 1

ORGANIZATIONS

INTRODUCTION

Theories of human groups have been developed by students working from two quite different points of view. From the first of these human groups have been endowed with an implicit independent existence, and have, in effect, been personalized. That is, human groups have been treated as if their mechanics of operation are not just analogous to those of the individual, but are, in fact, the same. The acceptance of this personification is a central assumption in much of the literature on groups and organizations. On the other hand, there are a number of writers who approach the problem considering the individual to be the basic unit they are studying.

The primary interest of this chapter of this thesis is to understand the acceptance of an innovation on a societal dimension. At this scale one sees organizational manifestation of innovation acceptance. Since both sets of theory originate from two quite different starting points, and invariably lead to different analyses and conclusions, a determination of the appropriate perspective, and its consequent analytic properties, is necessary. This problem will be addressed in this chapter by focusing on the definition of organization, with particular attention to organizational typology, and laterthose aspects of organization theory which apply to institutions will be dealt with.

ORGANIZATIONS DEFINED

Organizations have been defined as social units devoted primarily to the attainment of specific goals.{1} This definition, however, immediately forces one to question whether an organization can, in fact, have goals.

I have problems in accepting this proposition, although Karl Deutsch, building on concepts developed by Norbert Wiener, expresses a view which supports this concept of implied personification:

> "Communication ... makes organizations; and it seems that this is true of organizations of living cells in the human body as well as of organizations of pieces of machinery in an electric calculator, as well as of organizations of thinking human beings in social groups ... Cybernetics suggests that steering or governing is one of the most interesting and significant processes in the world, and that a study of steering in self-steering machines, in biological organisms, in human minds, and in societies will increase our understanding of problems in all these fields."{2}

Consistent with this implied personification, Deutsch says, "The will of individuals and groups can be paralyzed by destroying their stored past information".{3}

To accept that a group can have 'will', however, one must accept the concept of group mind. Despite his communication theory of organizations Deutsch does not go as far as accepting this. Rather, he posits: "All we can say now is that the question (of transferring mind) is again open, in a way in which it was not open thirty years ago."{4}

In contrast, Lawrence and Lorsch reject this notion completely:

> "(One tends) to think of organizations as having a purpose, but this is not literally the case. <u>People</u> have purposes; organizations do not. A simple organization may, of course, specialize in one thing such as the manufacture and sale of shoes. We call this its purpose, but this is acceptable only as a shorthand way of speaking."{5}

They define <u>organization</u> in this way: <u>an organization is the coordination of different activities of individual contributors to carry out planned transactions with the environment</u>.{6}

Thus, there are two quite radically different points of departure, suggesting the possibility that any conclusions reached, based on one assumption will be in opposition to those based on the other. Thus the importance of definition is inescapable, and the question of organizational 'goals' is central to this task of definition of _organization_.

However, for one to accept that only an entity conscious of its own will can have goals, and that only individuals have this consciousness, (as is my inclination) the contrary position must be confronted, and refuted.

An entity with goals is responsible for any actions taken to reach those goals in proportion to its intention to accept the effects of these actions. Only individuals can be said to exhibit this quality of responsibility, or conscience. To say otherwise would be to make the organization, apart from its component individuals, responsible (_eg_. absolve Eichmann), or the individuals equally responsible for the 'actions' of the organization (_eg_. all Republicans are responsible for Watergate); both situations are obviously absurd. It is in this connection that corporations are, by legal _fiction_, individuals --- and by this definition are forced to a responsibility which is otherwise not an intrinsic (or defining) property. Yet, in the practice of law, there _is_ a recognition that this is fiction, through the apportionment of responsibility among organizations (_fictional_ willing individuals) and persons in organizations (actual willing individuals). Take for example the following legal determination:

> "Last week the grand jury handed down an eleven count indictment charging (two) companies and seven of their high executives with conspiring to rig bids for contracts ... Each (executive) faces charges of anti-trust violations ... If convicted of the anti-trust indictments, the men will be subject to maximum three year prison terms and $100,000 fines each."{7}

Very rarely has the implication of responsibility been considered by students of organizations. Haworth{8} has, however, confronted this problem, and has concluded that organizations <u>do</u> act, because they <u>can</u> be held responsible for actions. He argues that assertions that organizations are collections of individuals is 'reductivist', and that organizations are trivialized if, at certain times, we do not take literally statements about organizational acts.

> "The responsibility inheres in the organization rather than its members as a result of two features of the act: first, that the act represents an outcome of that pattern of functions which constitutes the organization's form, and secondly, that, in the main, the quality of the act is unaffected by the personal qualities of the individuals who participate in its performance."{9}

Haworth develops the concept of organizational "form" and "content". <u>Content</u> is the personnel and tools, <u>form</u> is "the system of jobs which the personnel and tools ... carry out."

{10} Further, "acts ... are quite commonly repeated even though the individuals who participated in the first ... act are replaced by other and very different individuals."{11}

Haworth argues that in asserting that organizations cannot act "the fact of organizational responsibility is not communicated"{12}, and that this is absurd because it denies the fact that "there are occasions when a change of ... personnel does not appreciably change the acts of the organization".{13} Thus, in Haworth's view, organizational responsibility resides in its form, not in its content. Replacement in the content dimension (personnel and tools) does not change the form dimension (organizational action). Because of this continuity (form surviving content alteration) the organization carries the responsibility. Stated another way, form prompts content action. Because of this causal relationship, he believes form eliminates responsibility, perhaps even all the responsibility. Thus:

> "To attribute an act to an organization is to identify the organization as responsible for the act so that, if the act is desirable, the organization will be credited; if it is undesireable, the organization will be blamed; if we wish to eliminate the act, the organization will be changed; and if we wish to maintain the act, we will maintain the organization."{14}

Thus, he asserts that individuals are defined by the form in which they reside. The contrary view (which I hold) is that actions, not form, define the individual. Thus, we find that Haworth's assertion is not supportable because individuals in organizations are _not_ replaced by very different, but rather by very _similar_, individuals. When the personnel in an organization change, they are replaced by people who, to some extent, are prepared to perform the same actions. Thus, while a person may be replaced by someone who is very different in say, personality, the two individuals are similar insofar as the replacement performs the same actions. This would suggest that change is thereby impossible: replacement of people by 'similar' people yields the same actions in the same organizations. However, another dimension of similarity between replacement and replaced ensures that change _does_ take place, namely the ability of each to perceive and evaluate the correctness of their actions.

At this point I would like to introduce the concept of _iterative perception change_ to explain the assertion that change can be ensured by similarity. This concept is similar to Charles Darwin's _correlated variation_, by which he means "that the whole organization (_sic_) is so tied together during its growth and development, that when slight variations in any one part occur, and are accumulated through natural selection, other parts become modified."{15}

The concept of iterative perception change attempts to show how the actions of any member of the group are affected by the actions of the other members. Each member has a perception of a correct role, a perception which is created in two ways. First, the individual can be informed by a hierarchical superior (_i.e._, someone in higher authority) what the correct actions for that role are. Second, the member is informed of the correctness of action by an awareness of the actions of peers. The hierarchical superior is, however, also affected by his own awarenessof the actions of subordinates, to the extent that he can impose a definition of correctness which conflicts too much with what they will accept.

These two forms of the perception of correctness are not derived from 'formal' and 'informal' dimensions of organizations. An organization is _formal_ insofar as the imperatives of the superior are more important than peer pressure, but in both dimensions of organization both types of interaction take place. A peer can be a superior when he has some preceding knowledge (creating a superior/ subordinate relational mode), while a superior can be a peer when the relationship is evaluated in terms of personality, a levelling mode. Thus, subordinates also evaluate the 'edict' of a superior in terms of the perception each has of the actions of others, both formally and informally. Thus, <u>any</u> individual in an organization will iteratively affect, and be affected by, the perception he has of the correctness of any action, insofar as it is exhibited in the actions of others. His willingness to perform these actions (and, therefore, accept responsibility for them) is conditioned by his own values, and how much he perceives a congruence between them and the overt expression of the values of others in their actions.

Thus, while the statement, "I did it because everyone else does it," may be the reason why values in conflict with those of others are changed, it does not absolve the individual concerned from the responsibility for his own values. If, on the other hand, he chooses to maintain his own values, he remains apart from the group. In this way, individuals are rarely replaced by 'very different individuals'. When individuals <u>are</u> replaced the 'actions of organizations' are, to some extent, changed as perception of correctness is iteratively changed, regardless of degree of individual difference between replaced and replacement.

Thus, in contrast to Haworth's argument that organizational change is implemented by form alteration, any analysis which depends on organization members alone having the consciousnes necessary for the assumption of responsibility, has the following implications:

i change occurs through a change of members

ii changes in form are evidence of changes of will.

Both are explained here by the concept of iterative perception change. The attribution of goals to an organization --- as encountered in conventional parlance --- appears, then, to be no more than a locution whereby the task of speaking of the organization as a whole with interdependent parts has been made easier by the attribution of human traits to what is, in effect, an intellectual construct --- a collective noun.

To take the analysis a step further I would like to distinguish between 'goals' and 'purposes'. <u>Goals</u> are internalized preferences, developed without compromise with any external entity. <u>Purposes</u> are uses to which an external entity can be put to further those goals. (<u>I</u> have goals. Organization 'x' has purpose insofar as it helps me achieve those goals.)

All viewers of an organization are, by virtue of the act of viewing it, external to it. Hence they may view it in terms of purpose, assessing the value of their relationship to it in terms of the congruity of their goals and the uses to which the organization may be put. In this way the same retail firm will be perceived as a source of supply by a customer, a source of income by an employee, a customer by _its_ sources of supply. The staff member, who is generally regarded as a _participant_, is also an _outsider_ when he views the firm as having a purpose for him.

This last begs the question of what exactly are the boundaries of an organization? Who are the participants? Who are the outsiders? Etzioni, who accepted the concept of goal directed organizations, confronted this problem in terms of the _intensity_ of the individual's participation, thus avoiding the 'universalization' of the organization which follows if those whose involvement is low are classified as participants. If one includes the customer of a firm as a participant (as March and Simon did {16}), then one is hard put to locate its limits, for who is not in the position of potential customer? Etzioni's delineation avoids this problem:

> "We ... see as participants all actors who are high on at least one of the three dimensions of participation: involvement, subordination and performance ... Customers and clients ... who score low on all three criteria, are considered 'outsiders'."{17}

If one, then, considers the organization to be incapable of having goals of its own, but rather serving the purposes of the participant/viewer, then the definition of organization posed at the head of this section is unacceptable. The following seems a more appropriate statement:

> An organization is a concrete social unit in which there is a coordination of activities, resulting from a congruence of purposes of all participants with the imperatives of higher order participants to optimize the unit's relationship with the external environment.

This may be shortened, insofar as 'coordination of activities' and an 'optimal relationship with the environment' may be inferred from the existence of participants. Thus, _an organization is a concrete social unit in which there is congruence of purposes of all participants with the imperatives of higher order participants_.

A TYPOLOGY OF ORGANIZATIONS

Extra-organizational:

To avoid the complications of anthropomorphizing organizations into sentient, goal-directed entities I will use _role_ instead of _goal_, implying thereby that the organization is being viewed as having a place in relationship to its external environment, role being the mode of expressing its convergent purposes. Each individual viewer will see the organization as having a different function, the iteration of perception not having reached stasis. But this is as one would expect, there being few organizations with functions so explicit that every individual will perceive them in the same way.

It is not simply difficult, rather it is impossible to state with certainty what _the_ role of any organization is. Yet we do it all the time. Few would be hard put to state the role of, say, the Communist Party, or the Catholic Church. Participants and outsiders will, of course, have widely divergent opinions, and even within them there will be participants whose ideas will conflict. Yet we continue to make decisions on the basis of this broad 'role', estimating it in terms of present evidence of actions relative to the organization's 'end product'. What this end product is, however, is just as dificult about which to find agreement.

In fact, attempts to distinguish between organizations on the basis of their relationship with the external environment will always be limited by this problem of delineating exactly what the relationship is, in such a way as to find agreement among all observers.

One other approach is to concentrate on the nature of internal-external interactions. Regarded in this way a particular organization can be viewed in terms of the mechanics which make it work (or not work) so that the end product which is important to an outsider (among however many end products there are) will be at his disposition.

Thus, for one outsider the end product of an organization may be its education system, for another it may be its political power. It should be sublimely unimportant to each that the other product is there, except insofar as it affects the outcome of the desired end product. Thus, the question of what the relationship to the external environment is is no longer a matter of speculation or contention. its relationship to the individual outsider is prime. What does matter to him are the mechanics of organizational structure which produce the end product so that he can use the system to increase his benefits from it.

But this trivializes the whole nature of the discussion, for in concentrating on the evaluation of the organization by outsiders in terms of its purposes for outsiders, it becomes so multi-functional that no evaluation can be accepted by all students, observers, or outsiders which can be general enough to apply to any other organization.

Intra-organizational:

If, on the other hand, one were to concentrate on intra-organizational fulfillment, it may be that a limited number of typologies will emerge which are general enough to provide insights which may, _then_, be applied to the perceived purposes of an outsider.

Fortunately, the definition of organizations (as individuals who view the organization as helping them attain those goals.

No organization will be the only mechanic for their attainment. An individual may have as _one_ goal a life secure from indigence. He may work as a taxi driver to survive, and buy lottery tickets to get rich. His role as a taxi driver may limit his chances of reaching his pecuniary goal compared, say, to working part-time and studying medicine. But he has other short-term goals which conflict with this, and which affect his long-term goal. Thus, goals remain internalized preferences, developed _without compromise_ with any _external_ entity (but not without compromise with the individual's other internalized preferences).

i. Compliance Typology

Congruence of purposes is different. It _is_ a process of compromise or trade-off. A participant gets from the other participants by giving to them in a way that there is a congruence between benefits and costs which is acceptable to all. This is, in effect, basic to Etzioni's concept of compliance which is the foundation of his work, A Comparative Analysis of Complex Organizations. Though, for Etzioni, 'complex organizations' means 'complex bureaucratic organizations', he has placed his investigation within the widest context possible, so that his study of compliance contributes to the study of social order in general.{18}

For Etzioni compliance is "universal, existing in all social units"{19}, and (if one accepts the analogy in Norbert Wiener's work) it coexists with information transfer to contribute to a mechanism whereby the organization is steered to fill some role(s).

Congruence of purposes is the relative stasis which results from the interaction of power, information, and compliance. In relatively few (if any) organizations will the participant with more power exhibit no compliance with the lesser power of the participant who exhibits greater compliance. The assumption that power is exercised in only one direction limits the concept of organizations to the most simplistic model of information transfer. While the concept of congruence of purposes depends on the complex process of iterative perception change, it does not negate the fact that power is exercised unequally. Thus, the concept of compliance, which for Etzioni "refers both to a relation in which an actor behaves in accordance with a directive supported by another actor's power, and to the orientation of the subordinated actor to the power applied"{20}, is an accepted abstraction of the relationship between participants.

<u>Power</u> he defines as "an actor's ability to induce or influence another actor to carry out his directives or any other norms he supports", and is exercised coercively, remuneratively, or normatively.{21} <u>Involvement</u> refers to the psychological investment of the actor in the organization. The intensity of the involvement may be high to neutral, the <u>commitment</u> (Etzioni uses <u>direction</u>) positive tonegative. Commitment can be negative or positive because it is based on one's assessmenmt of how well one's purposes are served by participation in the organization. Involvement exhibits itself as a 'parabolic' function of the parameters of intensity and commitment. Thus, while it is possible to be highly positive or highly negative, it is only possible to be low and neutral.

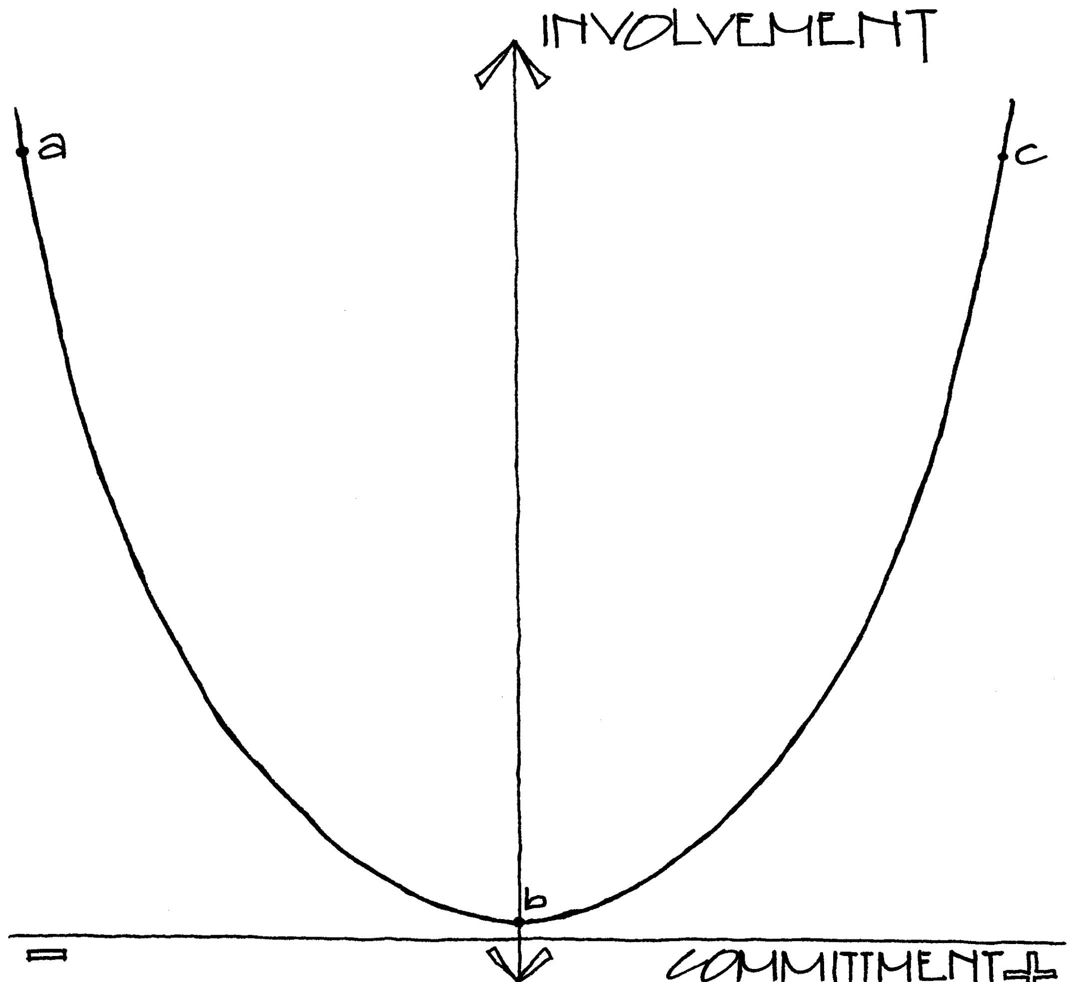


FIG. 1 COMPLIANCE POSITIONS

Given these definitions we can, following Etzioni, abstract three discrete positions (accepting the parabolic continuum):

a. alienative --- high/negative

b. calculative --- low/neutral

c. moral --- high/positive.{22}

He then relates power and involvement to present an organizational typology of compliance relations, as follows:

<u>Typology of Compliance Relations</u>

Power (of superior)	Involvement (of subordinate)		
	Alienative	Calculative	Moral
Coercive	1	2	3
Remunerative	4	5	6
Normative	7	8	9

and hypothesizes that the diagonal relationships, 1, 5, and 9, have a compatibility (he uses the term <u>congruence</u>) which the others lack.{23}

This incompatibility becomes obvious, not simply in the dificulty of finding stable relationships of this nature but, rather, in the incongruity of purposes which such relationships imply. There are six of them:

i. coercive/calculative

ii. remunerative/alienative

iii. normative/alienative

iv. coercive/ moral

v. remunerative/moral

vi. normative/calculative.

In the first case the higher order participant (the one with more power) uses force, and the lower order participant complies calculatively. The implication is that the amount of coercion is so low that the complying participant can extract benefits from his compliance. In the second case the remuneration is too low. (The first is seen in some prisons, the second in many employer/employee relationships.)

The third case results when the norms of the more powerful participant are in conflict with those of the compliant participant (the hierarch/heretic relationship, and the police state). The fourth is, at first difficult to conceive except for relationships that are analogous to the sado-masochistic, except that this is a power/compliance interaction that many regulators expect from regulation.

The last two have implications of a cynical use of others that is not uncommon, and which is exhibited in the pragmatic religious attitude: "I'll (you) be good and then I'll (you'll) be successful".

None of these is impossible, but there is an inherent instability in each, and Etzioni hypothesizes that this instability results in ineffectiveness which is only reduced by a movement towards compatibility.

> "(Compatible) types are more effective than (incompatible) types. Organizations are under pressure to be effective. Hence, to the degree that the environment of the organization allows, organizations tend to shift their compliance structures from (incompatible) to (compatible) types and organizations which have (compatible) compliance structures tend to resist factors pushing them towards (incompatible) compliance structures.{24}

ii. Typology of Function

An organization can be sub-divided into two groups, that which performs <u>line</u> functions, and that which performs <u>staff</u> functions. While the functions take place at different points of contact between the organization and the external environment, it is the internal relationship between line and staff which is important here. The concept of line and staff has been drawn from military terminology (the line fights, the staff supports the line), and has been applied to commercial organizations where the line sells and the staff supports. There are <u>two</u> aspects of the line function in commercial organizations, production and sales, which may be applied analogically to all organizations. Both contribute, in quite opposite ways, to the relationship between the line and the external environment, (which is not the same as the relationship between the <u>organization</u> and the external environment).

The function of the 'sales' group, for all organizations, is the maximization of external support through the <u>maximization</u> of the rate of exchange of 'support' for 'product'. The function of the 'production' group is to supply 'sales', and extract components from the external environment, while <u>minimizing</u> the rate of exchange of 'support' for component. The staff function is the maintenance of an efficient organizational structure so that the line function can be optimized.

While there is a symbiotic relationship between staff and line, there is a dichotomy of interest as well. The dichotomy stems from the fact that, by definition, the staff function is a throughput function, while that of the line is an input-output function. For the maximization of benefits as far as line personnel are concerned the ratio of input (<u>i</u>.<u>e</u>. work) to output should be minimized. For the staff personnel to benefit the volume of throughput (<u>i</u>.<u>e</u>. work) should be maximized, without regard to output.

Thus,in any organization where the staff function grows to outweigh the line, the congruence of purposes between line and staff personnel is in a state of interrelational imbalance. This situation is uncommon in most commercial organizations (except perhaps monopolies), where the micro-economic rationalization of the market tends to optomize the relationship in terms of effectiveness.

In contrast to incompatibility of compliance, which results in an incongruity of purposes which forces the structure towards compatibility, incompatibility of function tends to result in the formation of a 'new' organization, new (or changed) in that incompatibility of function causes the purposes of the higher order participants to be less dominant than they were. The movement towards compatibility of compliance, on the other hand, tends to reinforce the original purposes of the higher order participants.

In more 'institutional' organizations, (for example, hospitals, schools &c.) certain normative aspects tend to intefere with the process of economic rationalization. The staff group, which sees personnel growth as beneficial, can take advantage of the importance given to these normative, non-economic values. The growth of the staff function will cause the importance of the line function to atrophy, given certain changes in the external environment, and the congruence of purposes will find a new equilibrium in a deviation from the original perception of the purpose of the organization.

Thus, peacetime military organizations, government bureaucracies, church hierarchies, tend towards the conservation of a _status quo_, whereas the original perception of the purpose of the organization of which they are a part was the correction, or change, of part of the external world which was perceived as not worthy of conservation.

iii. Compliance/Function Typology:

The idea of a conjunction of the compliance and functional typologies is tempting. It presents the possibility of a new, richer typology which may suggest new compatibilities.

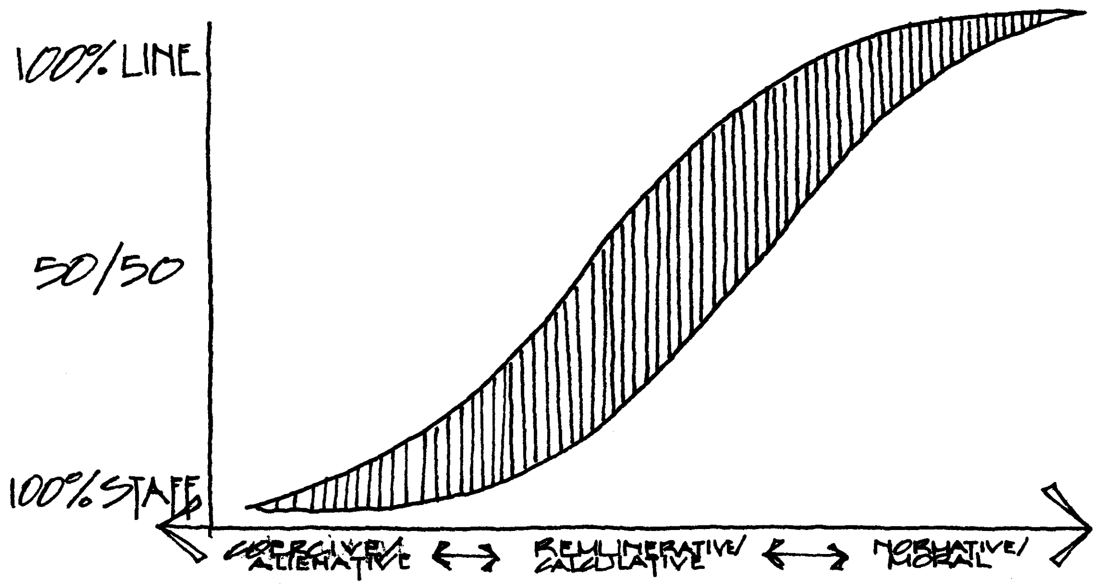


FIG. 2 FUNCTION/COMPLIANCE INTERACTION

This figure illustrates the typological interaction of function and compliance, and suggests that:

i coercive/alienative organizations tend to rely more heavily on staff functions, <u>or</u> organizations which are predominately staff organizations tend to rely on coercion to maintain compliance

ii remunerative/calculative organizations tend to have a 'balance' of line and staff functions, <u>or</u> 'balanced' organizations tend to function through a reliance on remuneration more than on any other method to maintain compliance iii normative/moral organizations tend to rely less on the support of a staff group, <u>or</u> groups which have little or no staff support are maintained by the moral commitment of their participants.

A corollary of this is that as the shift away from coercive/ alienative, through remunerative/calculative, to normative/moral occurs there is a similar shift away from the dominance of higher order participants towards the elimination (or vestigial existence) of the superior/ subordinate relationship.

The correspondence between compliance structure and functional structure is not one-to-one (<u>i.e.</u> not <u>all</u> coercive/alienative organizations are predominately staff, <u>&c</u>.), but incompatible correspondence is highly unlikely, although possible. A movement away from compatibility results in an organizational instability or ineffectiveness which can be resolved in one of three ways:

i the organization ceases to function

ii the organization shifts back towards compatibility

iii the organization shifts towards a remunerative/calculative compliance.

In a coercive/alienative organization, in spite of the power of the higher order participant, peer pressure tends to work _actively_ against the acceleration of innovation acceptance. In the 'balanced' organization peer pressure is a _more_ passive barrier to the introduction of innovation. Its power to retard acceleration, because of this passivity, can be overcome by the imperatives of higher order participants.

In normative/moral organizations peer pressure is the only real tool for innovation acceptance. There is, however, a tendency for this type of organization to be the carrier of only one change, a change which, once it is accepted by the broader society, is integrated into the routine on a remunerative/calculative, or even coercive/alienative basis --- but not on a normative/moral basis. That would imply a transformation not only of society, but also of human nature.

It would seem that real innovation comes before the organization is formed, and that the organization is the result of a number of individuals' positive evaluation of the change. (See page .) The effort of convincing enough others that the innovation is worthwhile, so that it will find a ready acceptance in society, is the normative/moral stage which lasts a short time in the case of a commercial innovation like the plastic shampoo bottle, or may take a long time when the innovation is to have a greater impact (_eg_. Christianity, Marxism).

Thus, the more 'line' the organization, the more it tends to be a vehicle for innovation, while the more coercive its compliance structure, the more it tends towards conservatism (at all levels) which rejects change. The routinization of an accepted innovation into the structure of an organization tends to take place at the level of staff/line balance where calculation and remuneration are the mechanics of evaluation.

A commercial organization, which is basically remunerative/calculative, relies for its effectiveness on a balance between staff and line. As it grows, however, it will formalize intra-organizational relationships and increase its staff function. This will demand certain regulatory mechanics which will result in some alienation. In a commercial organization where sales and production (_i_._e_., line) is integrated, and probably small, the staff function is minimal, and there may even be a normative/moral commitment to the product.

The hypothesis will bear further testing, but enough examples come to mind to allow one to question whether the apparent purpose of an organization can be its real purpose, if its functional structure is innapropriate to its compliance structure.

CHAPTER 2

INSTITUTIONS

INTRODUCTION

Organization theory is the basis of the understanding of how deliberately organized groups of individuals interact. Where a group is not organized, either formally or informally, organization theory makes no contribution to the understanding of the interaction of the participants.

It is the purpose of this chapter to describe and define entities which are extant but not organizational, and to extract from organizational theory those aspects of structure and function which apply to all groups, whether they are organizational or not, and whether there is a perception of participation by all who comprise the group or not.

The reason for the universality of this approach is to permit the evaluation of the architectural profession in all its manifestations, from membership in the most rigidly organized firm to the contribution to, or participation in, an institution as vaguely delineated as beauty. This evaluation will permit one to understand the relationship between participant and institution in terms of the narrowest, as well as the broadest, definitions of institutional role, an understanding which is essential before role can be redefined, or before the pace of this redefinition can be accelerated. The pressures which can be brought to bear successfully on an individual's perception of his institutional role vary, depending on the function which the institution performs.

This chapter will integrate the understanding of organizations and institutions to simplify later evaluation of the individual's role and how his perception can be changed. This will be done in the light of innovation acceptance, and how this acceptance is dependent on a redefinition of role --- or how a refusal to redefine is equivalent to a rejection of change. This is what makes innovation new. If it is not really different it slides into the individual's routine as a replacement for something already integrated, and does so without much difficulty. If it _is_ new it implies a restructuring rather than a replacement, and it is the redefinition and re-evaluation which is implied by this which is the obstacle to any real innovation.

INSTITUTIONS DEFINED

Institutions have been defined as discernible entities which carry, or are repositories for, social meaning.{25} They are manifestations of society's normative formulations which embody society's judgements, and provide a framework for the examination and resolution of situations which necessitate a determination of relative desirability.{26}

Delineation, beyond the limits of the definition given, has concentrated on function, activity, and role {27} as the evidence of institutional exchange --- relying in particular on description of the institutional entities which exemplify this exchange. Institutional entities have been divided into those which are organizations and those which are not ('non-organizations'). It is not implied that _all_ organizations, or _all_ non-organizations (when viewed from the standpoint of the individual observer, at least), are institutions, and their relationship may be expressed in the following way:

Institutions

Organizations　　Non-organizations

Both organizations and non-organizations are describable in terms of the formality of their structure, and in terms of their individual components. Thus:

Organizations

Formal　　Informal

Members

Non-organizations have a similar structure:

Non-organizations

Collectivities　　Social Orders

Persons

(<u>A collectivity is an indistinct entity with members characterized by a condition or quality of collective focus</u>, <u>eg</u>. the 'Women's Movement', 'white men'. <u>A social order is a societal disposition without specified members</u> {28}, but whose existence, being societal, depends on the participation of some individuals, <u>eg</u>. 'good taste'.)

The peculiar nature of the transformation of a societal entity into an institution is that there is a process of perceptual abstraction of certain attributes which embody the meaning structures of a society. Thus a member of an organization, or a person who is a participant in a non-organization, can be the institutional equivalent of the entity in which he is a participant insofar as he is perceived to manifest the qualities of 'membership', or the qualities of 'personality'. Thus the institutional arena is composed of <u>these</u> entities:

Institutions	
(A) Organizations	(B) Non-organizations
i. Formal Organizations	i. Collectivities
ii. Informal Organizations	ii. Social Orders
iii. Members	iii. Persons

Is the definition of an institution as 'a discernible entity which is the repository of social meaning' enough? Or can it be delineated further so that it still includes all the entities considered to be capable of being institutions, and yet express a more explicit functional relationship with the environment, in the way that the definition of organization does? Is there something which the following examples have in common (beyond their role as repositories of social meaning) and which can be extracted and delineated?

"Bell Telephone is an institution to most Americans." (A)i

"The Jets were an institution of more importance to the kids of 'West Side Story' than the police." (A)ii

"The I.B.M. executive is no longer an institution of importance in society as he was in the 'fifties'." (A)iii

"The movement for equality of women has become an institution of stature." (B)i

"The Plaza Hotel, and the 'round table' at the Algonquin, are New York institutions." (B)i

"No-one who's seen the head waiter at the Ritz in confrontation with a beige, double-knit, polyester leisure suit can doubt that 'good taste' as an institution is still alive." (B)ii

"Mae West! There's an institution! (B)iii

There are certain other aspects which must be taken into account, aside from the 'structural' exemplification. Consider the following: "The rigidly structured family of the Roman world was a formal organization whose male head held the power of life and death over all its members," and, "The Roman family is an institution whose values still pervade the modern family structure." The underlined verbs are not transposable. Thus, while the Roman family exists as an institution, the Roman family as an organization does not exist. The institution is abstract (though durable) in a way that the organization is not.

In this way both Mae West, Mickey Mouse, and even things that have never existed, can be said to be institutions: "Ptolemy's universe is an institution of such magnitude that it still manages to constrain man's conception of reality. Who can say that Einstein's universe will be any different?"

In what way, then, are organizational and non-organizational institutional entities similar?

Both are abstract constructs. Both are perceived to manifest a sharing of meaning by those who belong to them as _non-institutions_. Both are assessed as repositories of meaning structures against the meaning structures of observers, and the meaning structures of observers are assessed against their perceptions of those manifest in the institution.

An institution is an abstract social entity which is perceived to manifest shared meaning structures, and in relation to which the meaning structures of those who do, or do not, share them are assessed.

The dissimilarities are important too, for another reason. At this stage we have a definition of institutions which includes certain perceptual abstractions of organizations and non-organizations. However, if we wish to use the work of organizational theorists, we must know where to place limits on this use. There are two factors which must be considered. First: how dissimilar (or similar) are institutional organizations and non-organizations? Second: insofar as they are similar, how does organizational theory explain institutions, or will it be necessary to discard all organizational theory as inapplicable, and rely on (or develop) a parallel theory of institutions?

Three major points of difference emerge between organizations and non-organizations:

i organizations have discernible boundaries

ii members are aware of membership in organizations; persons are not necessarily aware of their participation in non-organizations

iii in non-organizations the imperative is subordinate to peer pressure (or iterative perception) in a way that is opposite to the mechanic of the organization.

Any entity, if it is to be said to exist, must be perceived to exist. It is perceived to exist by virtue of 'actions' which express its difference from the rest of the universe. One perceives a rock by virtue of 'actions' which express its difference, in the same way as one is aware of a social unit. Insofar as members of a group perform actions no different from the rest of the society in which the group exists it cannot be perceived to exist. Thus, for a group to exist, its members must perform actions which are different from the broader society's participants, <u>and</u> similar to the actions of other members. The awareness of what these actions should be is communicated to a participant in an organization, primarily from the imperatives of higher order participants, and secondarily through iterative perception. In a non-organization the importance is reversed.

But a non-organization includes participants who are not necessarily aware of their participation. Can iterative perception take place under these conditions? I believe it can. Take the expression 'rough diamond' as an example (a person of high intrinsic worth, but rude and unpolished{29}). This "high intrinsic worth" must be perceived to exist by virtue of the actions of the individual. These actions are defined as worthy by members of a group which perceives these actions to be correct for 'diamonds'. These members may, or may not, perform these actions (*i.e.* belong to the group 'diamonds'). The perception of the correctness of another's actions is enough. The 'rough diamond' performs these actions without having this perception. Thus, someone can perform the actions which contribute to the perception by others of a social order like 'good taste' without being aware of the social order. The perception of correctness by *all* contributors is not essential for the existence of the social order. What is necessary is the perception of correctness by observers.

Similarly for collectivities. I, as a white man, am perceived to be a member of that group by virtue of the 'actions' of being white and being male, actions over which I have no control. I may perceive these actions as neither correct nor incorrect, 'correctness' inhering in responsibility, for which an ability to control actions which can be evaluated normatively is essential. But that does not affect the existence of the collectivity, which exists by virtue of the perception of observers of the two necessary actions.

What do groups such as 'the Marine Corps', 'the Jets', 'white men', and (those who exhibit) 'good taste' have in common? In every case those who know they belong to the group know what is expected of them as participants, as do those who perceive the group as existing. The difference is that in the case of 'white men' and 'good taste' (both non-organizations) it is not essential that the participants be aware of participation for the group to exist.

Thus, iterative perception processes can take place at two levels, the level of the participant and the level of the observer. Organizational theory is the province of the first level, institutional theory of the second. But what is important is that iterative perception is applicable to both.

A further observation is also important. Insofar as individuals _can_ be aware of their participation in a group, _and_ be responsible for any actions which are the expression of this participation, the application of organizational theory to institutions is valid.

Thus, to use the example 'white men', organizational theory is totally inapplicable to the study of this group when the _only_ actions which define membership are whiteness and maleness. However, institutionally, the _abstract_ social entity 'white men' may be perceived to manifest particular shared meaning structures, whatever they may be (_eg_. '_white_ men', 'white _men_', '_white_ _men_', 'white men'). If anyone is perceived as sharing any of the values of the group, then the process of iterative perception is important because it defines the institution.

Insofar as individuals perceive themselves as sharing any of the values of any group the particular process of the formation of the perception of what is correct is, even when we speak of institutions, similar to the processes described in the section on organizational theory.

A third, and synthesizing point is that one's perception of what the shared values of an institutional group are will iterate with the perception of others, including the perception of participants as well as outside observers.

What this implies is that, in studying institutions, we may use the concept of <u>organization</u> analogically, in the same way that students of organizations should be able to use the concept of <u>individual</u> analogically. That is we must consistently avoid the idea of explicit goal directedness, and stay at a level that Deutsch was not happy with, yet which certainly appears to incorporate the possibility of change inherent in the concept of iterative perception:

> "In the view of many scientists ... evolution does not necessarily lead to one fixed goal, nor does it have to approximate any such single goal ever more closely. Rather, it is an open-ended process, containing the possibility of self-disruption or self destruction, as well as of a change of goals. Such a possibility seemed at least hinted at in the words of the New Testament, 'now are we the sons of God, and it doth not yet appear what we shall be'. Yet if this had been a hint of growth with no definite end, most theories of organizations persisted in not taking it."{30}

One may, then, consider the development of institutional entities of a society (in their role as repositories of meaning structure) as the evidence of the goalless development of the society itself. But insofar as the individual members of a society are caught between an awareness of the imperfections of the society, and the possibility of change induced disruptions, institutions are generally perceived as positive manifestations of things as they are.

A society, then, is as stable as its institutions exhibit a perception of the sharing of the meaning structures of the society itself by _all_ its members. The impossibility of this sort of state of static equilibrium ever existing creates 'gaps' which are filled by change or innovation. Thus, while change restores equilibrium (which is the _summa_ of individual's demands), the dynamic equilibrium to which it brings society is anathema to its members, because it implies continued change. ("New York will be a beautiful city if ever they finish it.") Institutions reflect the tendency of the mass of individuals in a society to react negatively to the risk inherent in change. And yet the fact of change is the most unchanging aspect of society.

INVENTION AND INNOVATION

There is considerable confusion which often arises in the discussion of innovation acceptance because of the confusion between invention and innovation and change. The first two concepts are quite similar, except that invention takes place at the individual (psychological) level, while innovation is the same process at the societal level of shared meaning, the level of the institution.

An invention is a thing, practice, method, &c., newly contrived by an individual, and invention is the action of contriving invention.

An innovation is a new thing, practice, method, &c., newly introduced into a society, and innovation is the action of introducing innovations.

Change is the effect invention has on the individual and innovation has on society.

The word invention is derived from venire, (Latin, _to come_) and has the sense of discovery, to come across, and does not imply that the inventor created the invention from nothing. The reliance on, what might be termed, 'cultural residue' is important, for it will be contended that invention (which will be used here interchangeably with physical and intellectual 'artifacts') is the action of reprocessing of 'things' which are already extant in the society.

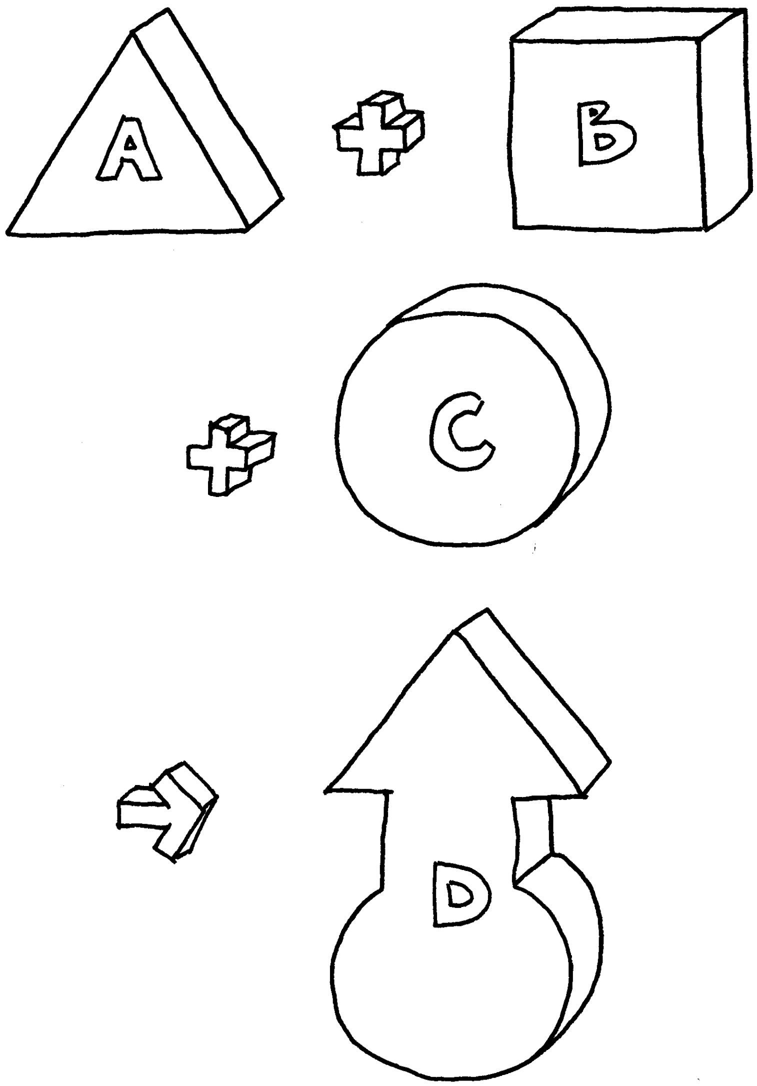
An invention, therefore, is an aggregation of 'parts' which exist before the process of aggregation. In considering the concept of invention, one must confront the concept of the 'whole' being greater than the sum of its 'parts'.

The 'whole' which constitutes the invention is not simply a _collection_ of 'parts', but a functional combination of them. Further, it is contended that the _combination_ is itself one of the parts.

Take, for example, the plastic bottle. For the process of invention to take place, or for an innovation to be introduced, the combination 'plastic' and 'bottle' must have a function for at least one individual (in the former case) or for a group of people (in the latter case). If, for example, the bottle had been washed up on a beach on a desert island, with one castaway as its population, its function as an unbreakable container of liquids could only be perceived if there were a perception of a functional synonomy between the bottle as container, and a hollow gourd (for example) as container, and if there were a perception of the functional value of the unbreakability exhibited by the plastic. This functional value may have been high for the original inventor and the society in which the invention was introduced, because of the avoidance of cut feet in showers perhaps, but to an individual unaware of glass (our island dweller, to whom gourds are plentiful) this value may be low. Thus, it is not impossible to think of the plastic bottle being perceived in terms of its transparency, its ability to be cut into pieces, and/or the symbolism of its shape, and to find it not at all perceived in terms of its function in the original society.

So, one of the parts that an artifact (physical or intellectual) must have if it is to be other than a 'thing' or a group of 'things' is <u>meaning</u> or <u>function</u>. Thus, the transformation of a number of 'parts' into a 'whole' entails the addition of meaning (or function) to an aggregation of 'parts'. Indeed, this meaning (or function) is itself one of the 'parts'.

Let



But, if:

$$A + B + C \neq D$$

then

$$A + B + C + x = D$$

This 'x', the attribute which makes D out of A, B, and C, must be present if D is to be present. If the concept of container (as exhibited in 'bottle') and the concept of unbreakability (as exhibited in 'plastic') are abstracted, or isolated from the rest of reality, the concept 'unbreakable container' exists only conceptually until a process of functional summation (or attribution of meaning) has taken place. This process is motivated by a perception of the need for the function which the summation fills.

> "Every artifact, such as for example a machine, can be understood only in terms of the meaning which its production and use have had or will have for human action; a meaning which may derive from a relation to exceedingly various purposes. That which is intelligible or understandable about it is thus its relation to human action in the role either of means or of end; a relation of which the actor or actors can be said to have been aware and to which their action has been oriented. Only in terms of such categories is it possible to 'understand' objects of this kind."{31}

Inventions may be the result of almost microscopic changes in awareness (such as the dissatisfaction of the individual who kept breaking shampoo bottles in the shower) or they may have had macroscopic proportions, and have resulted in theories as encompassing as the theory of evolution. In either case, however, the transitions through which the 'inventors' pass are the same.

First, some individual becomes aware of one of the 'gaps' in the structure of society by perceiving a 'lack' which exhibits itself in a sense of personal disequilibrium. Through a process of the synthesization of the available artifacts (drawing on the 'cultural residue' of contributions made by people alive now, or long dead) he becomes aware of the 'feasibility' of eliminating this 'lack'. If this 'feasibility' is transformed into 'possibility' by further experimentation an active state of 'desire' can replace the original state of 'need'. If it is acted upon the inventor can eliminate the 'need' and pass to 'gratification'. The transformation can be summarized; "I wish I had ...", "I could have ...", "I can have ...", "I want ...", "I have ...".

At this point the process of invention is complete. Upon its introduction to others than the inventor the invention becomes an innovation. It passes from the individual realm to the societal, and becomes part of society's collection of available artifacts. At this point society must 'pass' through a process which is similar to that of the inventor's transition from 'lack' to 'gratification' if the innovation is to become accepted. The social interaction change models (in particular those of Rogers{32}, of Lionberger{33}, and of Holmberg {34}) outline a societal transition from 'awareness' to 'integration'.

This transition is no different from the transition from 'lack' to 'gratification'. It was made, first, by the inventor, and now must be made by other individuals. Society's 'transition' is no more than an aggregation of the transitions of its individual members, whether individually or organizationally manifest. (Here, recall the earlier discussion on the definitional properties of organization.)

For the innovation to be accepted, individuals must have been aware of the 'gap', or have experienced the same 'need' as the inventor (even if this awareness came about as a result of the introduction of the innovation). This introduction fulfils the requirement of 'feasibility', The individual's positive evaluation of 'feasibility' takes him through the 'possibility' stage. 'Desire' follows once this evaluation has been made; a trial of the invention will complete the transition to 'gratification' and integration'. Societal acceptance will follow if this evaluation is performed by enough individuals --- separately and/or in organizational relation.

To a certain extent the simplistic nature of the model is obscured in the real world by the overlapping of numerous individual transitions. At one moment, while a few people have integrated the innovation into their routines, a majority may be in the 'awareness'-'evaluation' stage. At a later time a majority may have 'integrated' the change into the pattern of their lives, while a few stragglers are at an earlier stage. One's perception of the passage from 'awareness' of this concept to its 'integration' into a conceptual 'societal' transition. 'Society' does not exist; it is an abstract construct which has been 'invented', 'introduced', and 'integrated' to fill a 'need' which one, as an individual, shares with others to understand the _gestalt_ of one's own transitions, and how this _gestalt_ supports (or does not support) them.

At other extremes are cultures which cannot conceive of any reality in terms other than those of the individual:

> "'Truth', according to the (Dakotah) Indians, is what happens ... You cannot have the concept (of should), according to the (Dakotan). If you should do something, you do it. The (Dakotans) have no word for 'we'. 'We' puts you in with somebody. The (Dakotans) refer to 'I and you'. It's never 'you and I'. 'I' is the sacred word. 'Think' is conjugated only in the first person singular. No (Dakotan) presumes to say what another thinks." {35}

We have defined concepts such as _society_ to help us overcome the limitations of expressing aggregate 'actions' in individual terms, but we have gone on to endow this 'shorthand' with an implied reality which has become accepted through the habit of usage.

INNOVATIONS, INDIVIDUALS, ORGANIZATIONS AND INSTITUTIONS

The very existence of the concept of organization, and indeed of any organization, is a consequence of a 'lack' shared by the 'inventor' and others. At some innovations.

an concept of an individualistic world structure was not enough for one particular individual, who (in making use of the shorthand locution whereby the actions of individuals is used analogically for groups) introduced an idea, the lack of which others immediately (or previously) felt).

Thus, when we look at the process of innovation acceptance, we are looking at the swell of the aggregation of <u>individuals</u>' awareness., interest, evaluation, trial, adoption, and integration --- or their rejections of the innovation somewhere along the way.

The institutions we analyse can be formal or informal, conceptually abstract or rooted in the concrete, but in absolutely every case they are expressions of aggregations of individuals. 'Good taste', for example, is not a separate entity, but the aggregation of that aspect of individuals through which each is sensible to what is harmonious, appropriate, or beautiful. It becomes an institution in being perceived by individuals as the same aspect of all other individuals, insofar as the perception of this aggregation (not the aggregation itself) has an iterated impact on individuals. That is; the perception of the aggregation by one individual becomes part of the perception of another. It passes in a process somewhat akin to the process of dynamic disequilibrium to and from all individuals simultaneously.

The effect of this perception is exhibited in concrete, ways --- no matter how abstract the institution. The belief, or perception, of an individual is not something which has no relationship with the real, existing as it were _in vacuo_. It affects what the individual does, and is expressed in actions. The awareness of the correctness of the actions of 'all others' by 'me' is the stuff of which institutions are constructed.

When institutions are viewed as abstractions of certain aspects of groups of individuals with a perceived commonality of interest, they must also be seen as overlapping. In contrast to the physical organism (or even the organization) there is less discreteness. The institution 'Catholics' overlaps with 'blacks', with 'middle-class', with 'city dwellers'. So, while there is an acceptance by an individual of the actions one is expected to perform as a participant in one group (and an influence one contributes to that group's pressure on another), there is also a more than analogous iterative influence among groups as well.

When the process of innovation takes place the dissemination of the innovation ricochets back and forth, affecting and being affected by the group's members. This process is usually described as the 'learning curve' and depicts the rate of innovation diffusion. If the innovation is dropped, like a stone into a basin of water, into a finite group, the awareness of each individual reacts with others and exhibits this S-shaped pattern over time.

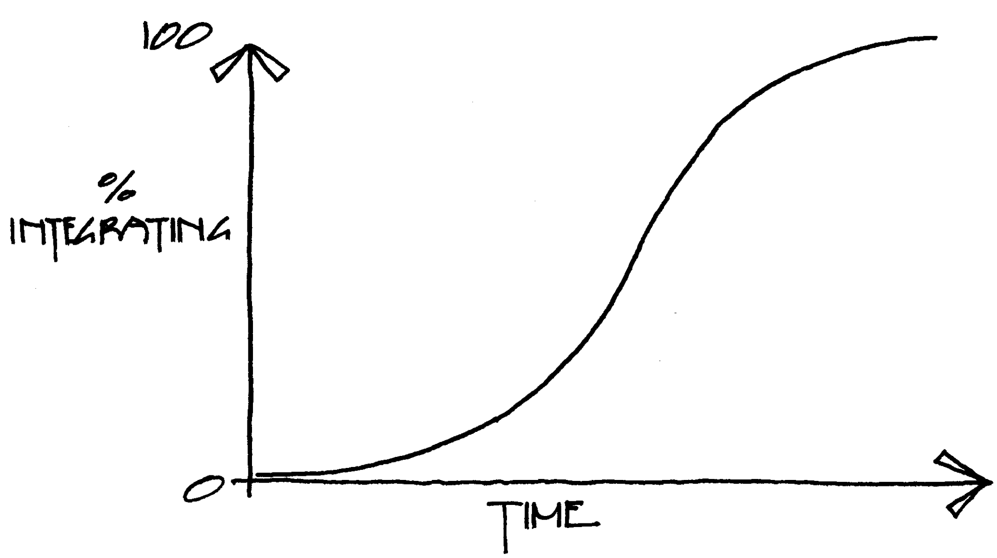


FIG. 3 'LEARNING' CURVE

First, one person (the inventor) makes others aware, and they affect others. The process speeds up until half the population has been exposed to it. At this point it becomes less and less likely that an individual in the group does not know of it. Eventually the curve flattens out until 100% of the group has been made aware of the innovation. This is the pattern which illustrates the regular acceptance of things like hula-hoops and yo-yos, which are disseminated by peer pressure.

When the group itself begins to be perceived by its members as a group, then the commonality of interest among the conjunction of individuals is expressed in their actions, as a conformity to a set of formal or informal 'regulations'. These 'regulations' can become 'imperatives' when they are imposed on the members by representatives who (depending on the organizational typology of the group) are formally, or informally, empowered by the members.

This brings us to the point of the extent to which 'non-organizational' institutional entities are influenced by the imperative. In a group where there is not necessarily an awareness of participation by all participants, this does not prevent these participants from being influenced by those who are aware of their participation. At the point when peer pressure and the imperative are equally important we are at the point of transition between 'organizational' and 'non-organizational' institutional entities.

In this situation an inadvertent participant reacts to what is perceived as <u>peer</u> pressure, 'peers' being members of some other group of which the participant <u>is</u> aware of membership. In this way a woman who dresses well may be evaluating the correctness of her actions by comparing hers to those of 'other women', or 'her friends'. Some of these, however, see themselves as members of the group 'well dressed women', and evaluate correctness in terms of the actions of other 'well dressed women'. Some of these follow rigorously the dictates of New York designers, who themselves are influenced by the acceptance of their clients, who are in turn affected by the actions of their peers. Thus, one may have a collectivity like 'well dressed women' which is certainly not an organization, but in which there is, to some degree, an unmistakeable influence of the 'imperative', even on individuals who are unaware of their participation in the group.

The purpose of institutional analysis is to make use of the knowledge gained from this analysis, to understand the way things work, or to make things work in a manner more to one's liking. For the 'higher order participant' this knowledge may be used in the manner of public relations to alter the perceptual abstraction of the institution's observer, so that while (as an organization) it may continue to do the same things that it has always done, it may be perceived as doing other things (or else the same actions may be perceived as meaning other things).

For those of us whose intention is to use the institution itself, the purpose of analysis is different. Two things can be done; the institution can be understood and used ('organizationally') the way it is, or the institutional entity can be changed.

If one is to use the institutional entity the way it is, one must understand the relationship of the compliance structure, and the functional typology, so that the entity's interaction with the environment can be used to optimize that of another institutional entity of which one, as a participant in that entity, desires. Another possibility is that, by emphasizing certain of the functional/compliance aspects of the 'manipulated' entity, one may lead it to perform actions which are not normally expected of it. (In this way the normally coercive/alienative interaction of the environment with the legal system may be avoided, and the system used to heighten the remunerative/calculative interaction of different sub-sets of the environment. Examples of this are the miles-per-gallon rating of cars, and the efficiency ratings of air conditioners.)

If the intent is to change the institutional entity (rather than the institution), the task is not simply an exercise in public relations. That is; it is not a question of altering what the institution means, but what the entity _does_. There are only two mechanics for this; manipulation of higher order imperatives, or manipulation of peer pressure.

<u>ACCELERATION OF INNOVATION ACCEPTANCE</u>

While the foregoing discussion of the process of institutional manipulation may sound cynical or hypocritical, it would in fact be cynical and hypocritical to deny that this is the very function of institutional analysis for those who wish to accelerate the acceptance of any innovation.

The 'bottom line' of institutional analysis is the <u>acceleration</u> of innovation acceptance. That is, one wishes to have the innovation accepted at a rate faster than will occur if the normal process of peer pressure is the only mechanic of acceptance. The 'demonstration program' is one way of exposing the innovation to more people, but it is not a method of acceleration. The effect of the 'demonstration program' is to increase the awareness of a few sooner than normal. Once the program ceases, however, the process of peer pressure continues as the only mechanic.

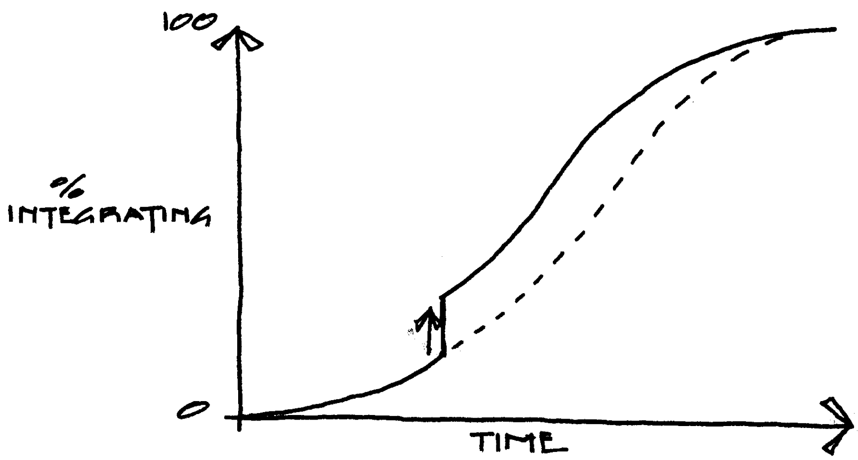


FIG. 4 EFFECT OF A DEMONSTRATION PROJECT

Real acceleration occurs when the <u>rate</u> of acceptance changes so that the curve 'becomes more vertical', not just momentarily --- as above --- but permanently.

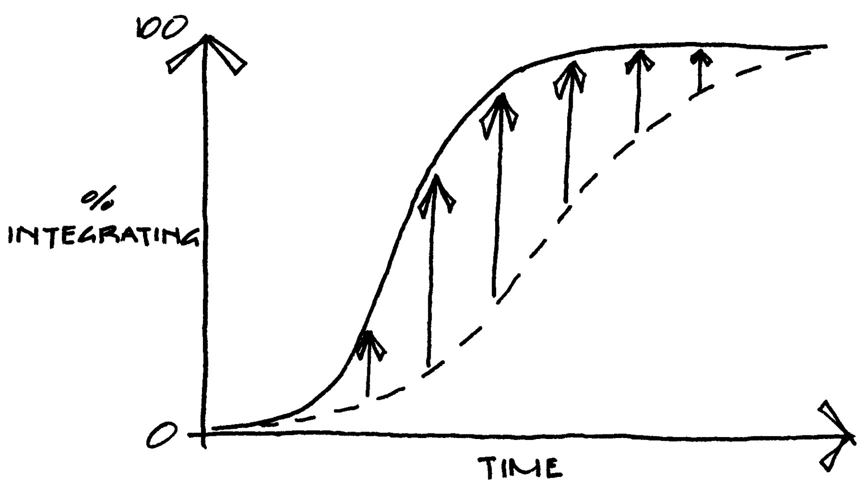


FIG. 5 EFFECT OF ACCELERATION

The most common, or typical, method to hasten the process of iterative perception is the use of peer pressure, whereby the actions of participants in the entity would affect the actions of others. This is the method that most advertizers use, and the framers of demonstration projects. It must, however, be emphasized that institutional analysis is not 'market research'.

However, institutional entities, to be made receptive to innovation, must be altered. That is, they must be made do what it is their function as institutions not to do --- act as the repositories of <u>new</u> meaning structures for society.

> "Institutional action is risk adverse; innovations will be avoided. Innovation institutionalization occurs through a process of repeating stages; (changing) the innovation from unknown to convention. The innovation has a different meaning and form in each cycle and for each institutional entity ... Successful innovation institutionalization is mediated through previously created institutional forms, notably personal information.{36}

The institution is altered when the awareness of the correctness of the actions of 'all others' by 'me' is altered. But awareness is no more than the perceptual impact of the actions of all others on individuals, iteratively affecting the actions of other individuals. Thus, the manipulation of institutions can be carried out by altering awareness or by altering actions. However, these are obverse and reverse. One's awareness is an awareness of actions. Thus, for any _acceleration_ of the acceptance of change to take place, the alteration of the awareness of what actions are correct, _through means other than iterative peer pressure_, is essential.

In any institutional entity which is _absolutely_ non-organizational (_i.e._ in which there is no perception among participants of higher order participants, or representatives) there is no possibility of acceleration, for in these entities information can only be disseminated by peer pressure.

However, in most cases, the human organizational structure is invested by its members with some primacy or importance in the perception of participants, and in the perception of their representatives, a primacy which overrides the importance of the individual member. The very act of 'belonging', as has been mentioned earlier, is the awareness of some commonality of interest which makes the individual compromise his purposes (be it ever so slightly) to those of the others who share the same interests, although goals are never compromised.

In some cases the primacy of the institutional entity is such that the individual becomes inconsequential. ("Ask not what your country can do for you; ask rather what you can do for your country.") In such cases, the extent to which the function of the entity is given primacy over individual purpose is seen in the rigidity of the iterative perception which lies behind peer pressure is the base against which acceleration is measured. If the representatives at the head of an institutional entity have been given the right to define correct role to the individual participants, then and only then can this curve (which reflects the interaction of peers) be made more vertical, by the manipulation of the perception of the representatives. This is because the participants have their perceptions of correctness changed, not by each other over time, but by those 'in power', instantly , by virtue of their right to impose imperatives. Peer interaction, then, becomes simply a method of contributing to the maintenance of acceptance, rather than mechanic of change.

CHAPTER 3

ARCHITECTURAL DESIGN AND SOLAR ENERGY

INTRODUCTION

This chapter briefly discusses the salient points of architectural theory. The intent here is to describe architectural design so that the impact of solar energy technology (both 'active' and 'passive') on the designer's role can be understood.

Solar energy is defined in terms of 'active' and 'passive' approaches. The different implications of each on the process of design is shown. 'Active' solar energy technology relies on mechanical systems to bridge the gaps between collection, storage, and consumption of energy. Because 'active' is mechanical it can be integrated into a design routine on a completely extra-architectural basis. Thus the acceptance of this solar innovation does not necessitate a role redefinition on the part of the architect.

A building uses 'passive' technology when the methods of energy collection, storage, and distribution are totally independent of mechanical systems. 'Passive' cannot be separated from the design process.

Twentieth century building has seen the introduction of mechanical aids which can provide a rigorously well tempered environment. This capability has resulted in the creation of new professions, in particular that of mechanical engineer, which have assumed responsibility for the fine tuning of the interior environment.

This sort of comfort <u>is</u> possible with 'passive' design. But, because it demands a mastery of mathematics, and an attitude towards the evaluation and integration of technical information which is not part of the competence and disposition of the contemporary architect, 'passive' demands a redefinition of the architect's role.

ARCHITECTURE AND DESIGN

There is an old (2nd. Century A.D.) definition of architecture, implied by Vitruvius in his "Ten Books on Architecture", as the conjunction of "firmitas, utilitas, & venustas", which have been translated as structure, function, and beauty (or sensual appeal). It is a definition which has stuck because of its succinctness. Though it has been argued about since the Renaissance, it continues to be useful, because it defines architecture in terms of three different yet united aspects which can be used as starting points for design.

Design is a process of correcting mistakes, not unlike the notion of evolution as a minimally controlled drift towards an uncertain end. (See page .) Though the designer has a general idea of where he wants to end, rarely is it more specific at the beginning of the process than the list of client requests, or program, which he is given as a point of departure. It is like the process of drawing. One sits in front of a piece of paper, pencil in hand, and some object to be represented. Any attempt at rendering a three dimensional object in two dimensions will result in some abstraction from reality. The fact that one is working, say, in black pencil on white paper means further abstraction. Thus, no matter how 'good' the result (accurate, comprehensible, recognizable, or whatever), it is going to be something quite different from the object.

From the moment the first mark is made on the paper one has made the first 'mistake'. A process of 'correction' begins as one 'steers' towards who knows exactly what, trying to make each 'mistake' equilibriate with all the others to produce something which is 'good', and which conveys the 'message' one set out to deliver.

The design of a building is somewhat similar. One does not have much more than a vague 'description' of the end at which one hopes to arrive. It is not a process of representation, nor is it even as simple as the process through which a police artist goes, when at least one person knows what the end product is supposed to be like.

The theoretician of design can produce a rigorously outlined description of the design process. But there are about as many of these descriptions as there are theoreticians. As rigorous as these outlines appear to be, they are no more than an attempt at 'linearizing' a circular, iterative feedback process, from a starting point which is unnecessarily overspecified. The abstraction unavoidably oversimplifies.

In the latter half of the nineteenth century (and again today, to some extent) a number of people, in particular John Ruskin, 'rationalized' design on the basis of *venustas*. One might call them '*aesthetic rationalists*'. Ruskin was derided by many because his theory implied that *architecture* was simply the application of decoration to building. But he was not the *naif* that many people assume him to have been. He was aware of the importance of *firmitas* and *utilitas*. He simply presumed that any architect would ensure that his building would stand up, and that it would enable people to do in it what was required of them. This he believed was no more than the province of the builder. For Ruskin the task of the architect was to transform _building_ into _architecture_, by the application of _venustas_.

In the early twentieth century fascination with the machine led many architects into a flirtation with '_functional rationalism_', (although this school had had its beginnings in the early nineteenth century in the work of J.A.Borgnis, to whom the pivotal purpose of architecture was utility). The most explicit statement of this attitude was not le Corbusier's famous aphorism, "A house is a machine for living in", which has been taken out of a most unrational context{37}, but rather Louis Sullivan's, "Form follows function". To many of these architects the question of 'beauty' was secondary to their delight in (or obsession with) function. Reacting to the apparent lack of function in decoration they rejected it completely, and reached a point where any building, even if it were a country outhouse (I believe the accepted paradigm was 'bicycle shed'), was seen as inherently beautiful if it just did what it was supposed to do.

Naturally, another group of architects believed that structural integrity was pivotal. These were, in fact the 'original' rationalists, whose roots went back to the work of Laugier in the eighteenth century. To hide a structural system behind applied decoration, or 'artificial' massing was anathema. An arch or column was used only if it performed a structural task, and was exposed (if possible) to express the forces which caused it to be there. If it was not needed it was not used. A later movement, _brutalism_, developed out of this, which had to do with a cohesion of 'structural rationalism' and the rationalism of building materials. 'Rationalism' meant the elimination of all that was 'unnecessary'. Thus the rationalist tried to limit himself to the most essential structure and the most economic (though not necessarily cheapest) materials.

None of these 'movements' need necessarily be thought of as taking place in a particular chronological order. Although there was a particular 'stylistic' component to each of these forms of rationalism (which implies that after a certain period they went out of style) there was a certain interrelationship among them all. One form of rationalism played against one or another, so that each was in a continual state of transformation.

One particular interaction was the work of one group which tried to integrate _firmitas_, _utilitas_, and _venustas_ on a basis of 'rationalism'. To members of this group 'aesthetic rationalism' appeared to be totally inconsistent and self-contradictory. But beauty in architecture was unavoidably important to them. However, by definition 'rationalism' reduced design to the essential. As beauty was not necessary for the building to stand up, nor for the practice of any particular activity within it, it was not rationalizable in itself.

Thus, out of functional and structural rationalism, and the concept of <u>integrity</u> (which had to do with the 'honest' expression of function and structure) a body of theory developed which attempted to account for <u>venustas</u>. Stated simply, it was posited that it was not only essential that the demands of structure and function be served; they must also be <u>seen</u> to be served. Function and structure had to be expressed. Thus, one made sure that the different purposes of different spaces, and the basic structural mechanisms, showed in the form the building took. This was enough, an attitude expressed at its most succinct in Mies Van Der Rohe's aphorism, "Less is more".

In this way 'structural-functionalists' incorporated all the Vitruvian triad into a theory that any building which really expressed the essential interplay between a rational structural system and a rational functional system <u>had</u> to be, <u>by virtue of this expression</u>, beautiful.

However, I do not believe in the primacy of any of the three definands, nor do I believe that the beauty of a building is related quite so simply to structure and function. At least, not to the rather limited definition of <u>function</u> which 'functional rationalists' use, limiting it to the function explicit in the program.

Planners have an expression, 'first cut', which implies a certain human-ness which is absent from the concept of rationalism. It is analogous to the first line on the white paper. In design it does not really matter where one starts, because whatever is done to begin is going to be changed anyway. I have made 'first cuts' in design on the basis of structural, of functional, and of aesthetic values. Whatever comes first, the introduction of the next of the triad always forces quite major changes. By the time the third is introduced the original concept is quite unrecognizable and the process has hardly begun, because it is repeated again and again. The iterative effect of each on the others goes on and on. In effect, it can continue forever. The process of design is never finished; it is only stopped.

If design were no more than this, however, one would be close to the structural/functionalist position. What really enriches the task of design is a different definition of function, and the scope over which one lets this definition range. To many architects, _function_ is the explicit delineation of particular activities expressed in the program which the client gives the designer. But a variation on the planner's question, "Who exactly is the client?", alters the concept of _function_ completely. I do not mean that the designer must consider himself as working explicitly for a constituency beyond the original client, but that an awareness of this client's role in the broader society is necessary before the concept of _function_ is complete.

Thus, while an architect is designing a building to perform a specific function for a particular client, he must be conscious that the client is part of the matrix of society. (Recall the black, middleclass, Catholic, urban dweller of the first chapter.) The 'client' may be a group of bank owners, and their building will have to permit a staff to perform particular banking functions. But the clients are also building owners, and as such have other roles which interact with that of bank owner, and which present the designer with a richer set of 'environmental' constraints Some of these constraints may be as formal and rigorous as adherence to the street and sewer grids, while others may be as informal as Edmund Bacon's "principle of the second man", whereby an owner (depending on the society) is expected to conform to the existing set of patterns of building form.{38}

It is this richness that 'functional rationalists' dismiss when they limit definition of function to the terms of the program. The presumption implicit in the dismissal of the expectations of the individuals who make up the society is the belief that tradition is no more than the detrius of a past which has no importance in a new world, a belief which makes of architecture a less than human art.

Architects and theoriticians of the 1960's and 70's (in particular Robert Venturi, with his, "Less is a bore") reacted against this. They expressed a belief that buildings, in commom with all of our artifacts, have to perform the function (among others) of communication. This has been dismissed as foolish by those who believe that the expression of function and structure produce all the beauty necessary or possible. The cynical among them have suggested that one might as well look for a message from the cook in a

Big Mac. But indeed there _is_ a message there; simply by virtue of their existence Big Macs contribute to the culture in as valid a way as the Metropolitan Museum of Art. In producing both, the culture is defining itself. Thus, any building is contributing to the definition of the culture within which it exists; this is its communicative function. It expresses, in some small way, the meaning, or function, of its society.

If a designer chooses to ignore this as part of the building's function, he is choosing to avoid some of the most challenging design constraints, and the most enriching possibilities. He may do just that, but misses out on most of the interplay of creativity and criticism which is essentially what the process of design is all about. What Robert Venturi calls the "complexity and contradiction of architecture"{39}(which in its very terminology is as far from 'rationalism' as possible) is the result of the interplay of the various aspects of a rich, rather overpowering environment. It is impossible to be 'rational' in the face of all this. The recognition that the contradictions of a society can never reach stasis is more than analogically expressed in the contradictions of a building's design. If the designer is aware of the _real_ functions for which he is designing, then the dynamic disequilibrium of these functions <u>cannot</u> permit any design to be rational, because rationalism implies the recognition as real of a stability which is not possible.

SOLAR ENERGY AS A DESIGN CONSTRAINT

When one begins the study of the design of 'solar' buildings there is a temptation to limit the definition of function to energy efficiency alone. Many 'solar' designers go so far as to presume that any change in lifestyle implied by the optimization of energy efficiency should be made, simply because conservation is morally good.

In "House Form, and Culture", Amos Rapoport presents and supports the hypothesis that socio-cultural determinants of house form are the prime determinants, and that a reliance on physical factors to explain form of buildings will leave one far from satisfied.{40} Many who accepted his position, however, have transformed energy efficiency into a socio-cultural factor by virtue of the morality of conservation , a morality of the 'counter culture' based on the assumption that less is, if not 'more', most certainly 'better'. This is not an idea which finds a ready reception among the vast majority of Americans. A change for the material worse in their way of life will be accepted only when it is inevitable, and not before. To most lay people the sort of change which morally committed 'solar' architects presume to be good because of the constraints on consumption, is unquestionably bad because of these very constraints. The inability of these designers to see this dichotomy has resulted in energy conscious design being viewed as a symbol of a less than desireable way of life.

The imposition of the demands of physical determinants on life-style will always be resisted until these demands are validated by circumstances which go beyond the moral committment of a few. Certainly these few <u>are</u> preparing others to cope with these circumstances if they come, but as long as these circumstances are only possible, and not inevitable, things will tend to go on as they are. Energy connscious design <u>can</u> fit into the way of life with which most are comfortable, and contribute to its continuation. While this <u>does</u> make energy efficiency one determinant among others, it does not relegate it to the position of unimportance it had in design before. The problem for many architects is that the very fact that it is included at all complicates the design process considerably, a point which will receive attention later.

Solar energy has been presented to us as part of an ancient folk wisdom, forgotten in our mad rush away from the good earth. We have but to return to the simple values of the past, building in the way our ancestors did, for architecture to be really responsive to our needs. This is a romantic oversimplification of the problems we face, for the societies which developed these simple systems were quite simple themselves, specially when compared to the complexity of modern industrial urban society. The solutions which worked for their problems do not work for those of our complex culture.

Because of its separation from all but the most immediate environmental impacts, our society has developed a highly sophisticated, technological infrastructure which, as is the case with any successful societal artifact, has been integrated into the culture at many levels. The food we eat, the clothes we wear, and the buildings in which we live are, because of technology, only marginally similar to the equivalent products of fifty years ago. We depend on methods of food preservation which were unheard of then. Clothing is a product, in part, of the chemical industry. The buildings in which we live and work evidence a technology of the utmost complexity. The high-rise office building and apartment tower, essential to the functioning of our society, are far removed from the self-contained farmhouse. The architectural folk wisdom which made the pueblos perfect reactions to the physical and socio-cultural determinants of their time, is not applicable today, except at the level of the most 'uninterdependent' structures.

Of all the professionals, architects seem to have avoided as much involvement with technology as possible, in spite of the fact that buildings are so much involved with the technological infrastructure characteristic of our contemporary culture. This statement seems to contradict an earlier comment about the technical complexity of modern urban buildings. In fact, it does not. The architect has little immediate personal involvement with technology because he has been led into a dependence on a number of relatively new professions by virtue of this complexity, in particular on mechanical and civil engineers, whose specializations have advanced as the technological command expected of the architect has retreated.

The architect, even in a period as late as Ruskin's, was part of a tradition of relatively steady change, and his meaning in the culture (while obviously open to a certain speculation, reflected in the conflicting theories which were developing) was fairly well defined. Building methods were much the same as they had always been, because materials were the same. Architects could rely on a tradition of structural methods which, compared to today's, were little more than a set of rules of thumb. With the development of elevators, concrete, steel, artificial lighting, mechanically controlled environments _&c._, the command of technical information which had to be synthesized into the construction of a building was beyond most of those who were capable of what, previously, had been all the 'correct actions' expected of an architect. Architecture remained what it had been, and did not change to incorporate these changes, because individuals in the profession were replaced by others expected to perform the same 'correct actions' (and, thus, by people who expected to have to perform only those actions).

Thus, in spite of all the arguments about 'structural rationalism' and 'structural functionalism', there are very, very few architects who know enough about mechanics and building materials to be truly rational about any system larger than the family house. In the same way, there are very, very few who understand the complex technology behind the maintenance of human comfort, which is the province of the mechanical engineer. Thus architecture remains very much what it was to John Ruskin, the integration of decoration and building. For Ruskin, that aspect of building which was not architecture was the integration of _firmitas_ and _utilitas_ alone. For most modern architects it is whatever is the province of the civil and mechanical engineer. The architect is trained to integrate their structuring and machining of the building with the function of the building. He will work with them to create a relationship between the massing, the materials, the mechanics. He can expose the duct-work, and paint it bright colours; he can decide to clad the structure in granite, or to go with bush-hammered concrete. But, in the end, he is a manipulator of *venustas* and *utilitas*, and is content with this role, not simply because of the fact that he is incapable of working at the technical level of the engineer, but rather because he is not expected to.

Unfortunately, the inclusion of energy efficiency as a design constraint has complicated the process of design in an extremely technical way. It requires the routine integration of *firmitas*, *utilitas*, and *venustas* on the basis of a definition of function which includes the program outline, as well as the broader definition of function discussed earlier. *But*, it must also include the maintenance of human comfort which was a responsibility of the architect in a tradition of less complicated structural problems, a responsibility which has become that of the mechanical engineer. There are three ways out of the problem. First, design can stay the same, and the architect continues to perform the same set of 'correct actions'. In this way solar architecture becomes the responsibility of a non-architectural expert. Second, design can incorporate the constraints of human comfort, but gets to be no more difficult. (That is, something else has to go; usually this means the sort of redefinition of function to eliminate anything which stands in the way of energy efficiency.)

The third way out is for the architect to accept the redefinition of function to include the maintenance of human comfort, and to expand his capabilities to permit him to be able to design in such a way that the integration of the Vitruvian triad incorporates comfort into *utilitas*. To many this means a reevaluation of their role, and as such, can be fraught with problems.

Technical training in mathematics, physics, and chemistry is necessarily limited by the demands of other aspects of architectural education which are important, and by the tradition of reliance on other professions. In most cases the architect's only exposure to technology is through the work of these other experts. To a very large extent this is the reason why 'active' solar energy systems, rather than 'passive', were the ones which started the movement towards solar, because the 'active' solution calls for no redefinition of role. In fact, 'active' can be routinized into the regular pattern of interprofessional practice with no more radical perturbation than the replacement of one mechanical system by another.

PASSIVE AND ACTIVE DEFINED

'Solar' architecture attempts to minimize dependence on external energy sources, other than sunlight, for the maintenance of human comfort in a building.

A solar building is defined as 'passive' when the methods of energy collection, storage, and distribution are totally independent of mechanical systems. 'Active' solar energy, on the other hand, relys completely on mechanical systems to bridge the gaps between collection, storage and consumption. A system is 'hybrid' when <u>one</u> of these two gaps is bridged mechanically. A more 'active' hybrid system links collection and storage mechanically; it is more 'passive' when the mechanical link is between storage and the locations of energy consumption.

While 'passive' solar design is unquestionably a more architectural approach, the facility with technical knowledge which is required for the integration of collection, storage, and distribution into the fabric of the building is immense, compared to the architect's normal routine of working with a mechanical engineer and designing the building around an H.V.A.C. system designed by him. 'Passive' design is absolutely integrated into architectural design. It cannot, as is the case with 'active', be handed over to an expert external to the process. Unless an architect is prepared to be educated (or reeducated) in the technical knowledge required for this sort of design integration he is <u>incapable</u> of real 'passive' design, for the maintenance of a rather rigorously defined range of human comfort depends on much more than the application of a few rules of thumb to a 'regular' design. It is for this reason that many architects have found it easier to 'go solar' with 'active' systems.

If the building is small, and he is designing the 'active' system himself, it will be, essentially, a building with a mechanical system similar to the one it replaces or supplements, with ductwork and fans for example, used in the same way. The major difference is the impact of the flat plate collector, which should not be a difficult constraint to deal with, as powerful as its impact on form may be.

If the building is large the system will be designed by an engineer. Within the constraints of this routinized setting, the architectural impact of the flat plate collector is basically similar to other technological impacts (elevator housing, cooling vents, _&c_.). The architect designs around an 'add on' technology, the understanding of which can be left to a technical expert, an engineer. The innovation of 'active' solar energy is, thus, immediately routinizable at the level of the design professions.

In contrast, 'passive' solar energy is a completely architectural concept. Because of the integration of energy collection, storage, and distribution with _firmitas_, _utilitas_, and _venustas_, it is essentially the separation of architecture from the routine reliance on the external technical expert. But one of the results of this reliance has been a history of tighter and tighter definitions of comfort, so that a building is now expected to provide a rigorously well-tempered environment. Designers, once cheap fuel and the technology essential for its conversion into useable heat and cool was available, not only gave up the responsibility for comfort; comfort was very quickly redefined. When fireplaces supplied the heat, then furniture, clothing, and even patterns of living contributed to define a level of comfort which most would find unacceptable today. The emergence of the technical professions permitted the internal environment to be so finely adjustable that we are now free to wear summer clothes throughout the year indoors, and furniture which would have meant pneumonia for its users a hundred years ago is the norm today. In passive design this well tempered environment has to be _entirely_ the responsibility of the architect.

REDEFINITION OF ROLE

Before he can accept this responsibility for the comfort of the building's occupants, the architect must reevaluate certain aspects of his professional role, and redefine what 'correct actions' are for that role. There are two barriers to this redefinition. First; as much as teachers and practicioners of design make gestures in the direction of this responsibility, the availability of mechanical environmental control, and of the technical expert to design it when the scale of the work calls for him, has limited the definition of the architect's role to one with which many are comfortable. Second; the acceptance of all responsibility for the internal environment implies a technical involvement which most architects are either quite happy to avoid, or incapable of, by virtue of the limitations of their training, and by the sort of person 'called' to the study and practice of architecture.

The design of a passive building, while in many ways similar to the regular design process, goes far beyond the application of a few simple 'rules of thumb', to produce results which the technical expert can refine. The architect _is_ the technical expert in this case. The 'passive' design process combines all of the features of regular design with what is essentially an exercise in rigorously applied mathematics acting as the governing design constraint. And (even when this is reduced to the use of programmable hand held calculators) this is the sort of constraint most practicing architects, who have developed a working routine with which they are comfortable, are quite happy to avoid.

Even the architectural student is socialized to accept a role created by the iteration of perception stabilizing at the level of artist. But this stability is not real stability, existing as it does in a _gestalt_ of dynamic disequilibrium. It is the constancy of change which this implies which will enable individuals who comprise the group 'architects and architectural students' to iteratively redefine 'correct actions' to incorporate a command of the technical knowledge necessary for the routinization of 'passive' solar energy. But this is the path of peer pressure, and the rate of acceptance will not be accelerated by dependence on this path alone. External motivation is essential for acceleration, and it will be one of the purposes of this study to suggest methods by which this might be done.

CHAPTER 4

A 'PASSIVE' DESIGN

INTRODUCTION

The purpose of this chapter is to present an abstract of a program and an example of a 'passive' design which illustrates that the acceptance of the responsibility for the finely tuned environment is not contrary to the architect's and client's concern with other determinants of design, in particular, form. To a great extent the manner in which 'passive' design was presented until recently meant that the constraint of energy efficiency was quite inimical to formal concerns.

Aditionally, and primarily, the purpose of the example is to illustrate the extent of the technical involvement required of the architect. The mastery of calculative techniques had an impact on 'massing' of the building, affected choice of materials, and influenced the treatment of the building's membrane.

The process of design did not, however, negate the 'intuitive approach, but rather adumbrated it. When a 'formal' decision was made intuitively its effect could be measured with exatitude. The scale of the change could be adjusted to ensure the thermal comfort of the users. This is the most important aspect of 'passive' design, for comfort is 'the name of the game'.

PROGRAM ABSTRACT

The Christian Herter Center, on the Charles River in Boston, is among other things a demonstration center for energy conservation programs, projects, and ideas. The directors of the Center want to add a restaurant to the original structure which will serve as a 'state of the art' demonstration of good energy conscious design. A number of students at MIT presented designs, among which the example presented in this chapter was one.

The following items constitute the salient aspects of the building program:

i the restaurant must be contiguous to the original building, and be a reasonable outgrowth of the main building in order to be acceptable to the Metropolitan District Commission, which owns the land.

ii indoor dining area 1300 sq. ft.

iii kitchen area is 400 sq. ft.

iv provide space for lavatories, coat checking, and waiting

v one or two levels may be used

vi a 'roll-out' outdoor light lunch area for Charles river goers is required for temperate months, which should have an informal 'picnic' atmosphere and a pleasant microclimate

vii the indoor dining area will serve light luncheon for river goers and workers in the surrounding offices between noon and 3 pm, and formal dinners at night between 6pm and 10 pm, six days a week

viii conferences in the center will be catered by the restaurant

ix space should not be taken from the interior of the main building

x existing parking should be utilized

xi the dining area should undergo 5 air changes per hour during service

xii air conditioners/chillers should be avoided

Other features of the program required that the restaurant be as exciting a place as its surroundings, while remaining sympathetic to the site (the moat surrounding an outdoor theater built onto and into a man-made berm, and the river). Any extra heat should be used in the existing building.

A schedule of kitchen appliances which produced close to 170,000 BTU's per hour was given, and this heat was to be recovered and used as necessary.

THE 'INTUITIVE'APPROACH

When one is asked to design a 'passive', energy conserving building the immediate reaction is to start thinking in terms of southern exposure, earth berms, underground structures, and building mass. However, there were features of this problem (the site, and aspects of the building's function) which were completely imimical to this approach. The view was to the north, which meant that northern glazing was unavoidable. The view to the south, of an arterial roadway, factories, and offices, was so unprepossessing that minimal south glazing was desirable.

The water table was two feet below grade. The site was completely flat, except for a berm which contained the storage for an 'active' solar heating system already serving the Herter Center. So underground building was impossible (even if the view were not important). Moreover, the main building was a simple (some might say boring) example of 1950's, International Style, structural rationalism. If energy conservation had not been an issue any addition would have called for a strictly formal approach based on aesthetic principles, unless one were simply to continue the original structure.

First: for cooling purposes an extension was needed beyond the north edge of the Center. This fitted in with the area requested in the program. The quarter circle was not big enough, even with the two floors needed to bring the addition to the height of the original building. Nor was it formally effective. Without the breeze catching extension to the north it did not end the original structure with any finality. It was very much a minor addition which needed this sort of exaggeration to have the effect that was necessary.

The glass roof had to be sloped to get rid of rain and snow, but against the strong statement of the long roof of the Herter Center with its striking reflective, black solar collectors, this slope contributed to the weaker statement of <u>addition</u> rather than to the stronger statement of <u>end</u>. A decision was made to surround the perimeter of the roof with a reflective glass fascia. This served the purposes of concealing the 'weak' slope, continuing the statement of the collectors, contributing to an apparent volumetric enlargement still needed to balance the 'weight' of the original, and at the same time provided a support for shading devices which would be needed in the hotter months. Aside from this, the metal structure needed to support this fascia could be

But, in spite of the conservation constraint, formal issues could not be ignored. The sort of addition which used the vocabulary of the obviously energy efficient building would have been an impossibly inconsistent, add-on attachment to the main building. For all these reasons the first cut was not made on the basis of energy efficiency, but on the basis of form. There was one other reason; a feeling that it was about time to see how much a 'formal' designer could get away with when constrained by energy efficiency. It was decided to go to an extreme in the first cut, to break one of the major rules of energy conscious design, and work with glass alone. It would be possible to work back from this if it were necessary, using solid walls and roof if heat loss or heat gain demanded it.

Starting with an initial form of a quarter circle, with a diameter equal to the width of the original building, a flat, glass-roofed structure was added to its east end (to minimize the effect of late afternoon sun. This form was then adjusted as constraints of taste, energy efficiency, and function demanded.

constructed of the same components which were used to define the bays of the Center, thus tying the addition aesthetically to the old building. Even the profligate use of glass repeated, in another way, the large glass surface of the original.

The location of the parking lot, and a decision to keep service roads to a minimum, called for service and client entrances to be on the south side, close to the entrance to the Center. This fitted into the constraint of the northern view, but necessitated some planting to separate visually the Center and service entrances.

Site planting was used for the same purpose, to keep the outdoor service area separate from the restaurant, at the same time serving to direct breezes into the wind scoop extension.

Finally, some formal manipulation of the perimeter wall served to express the functional separation of a possible bar area, and of the entrance area. The relatively isolated nature of the site reduced the impact of those broader aspects of function referred to in the previous chapter to the sorts of constraints outlined above.

ENERGY CONSERVATION AS A DESIGN CONSTRAINT IN THIS DESIGN

The decision to work with an all glass structure was made, to some extent, for reasons outlined in the section An Intuitive Approach, but what really generated the idea was a knowledge of the properties of Heat Mirror, and a feeling that this material could be used to give the energy conscious designer a freedom that many such designer believe no longer exists.

A glass building would have normally been unthinkable. But Heat Mirror, a treated glass with the ability to reflect heat, transforms the properties of a building membrane. Once light has entered a building glazed with this material, and has been transformed into heat on striking a non-reflective surface, this glass prevents it from re-radiating to the outside. In fact, double glazing with this material is, as far as heat retention is concerned, equivalent to a regular 2 1/2" stud wall with 1" of Fiberglas insulation. It has the added advantage of letting the sunlight in, and acts as an effective collector, whereas the stud wall acts only as a heat retainer.

Heat storage was handled by the use of eutectic salt tiles (Sol-Ar-Tiles) which were spread throughout the building, on floors and ceiling. They have nine times the heat capacity of concrete, and store the heat as phase change energy. In this way interior temperatures tend to stay close to 72^{O}F, if an ideal balance between glazing and tiles is possible, without the need for mechanical control. This building was allowed to drop to 45^{O}F before sunrise in winter, as no one is expected to use the main area until 11 am., by which time solar gain will lift the interior temperature to 65^{O}F. on an average January day. In this way the building acts as a completely 'passive' system, trapping light, and storing it in the location in which it is needed.

Additional heat was available from people and lights, as well as from recycled kitchen heat. A simple heat exchange system can return 65% of the heat exhausted from the kitchen, and can be stored in eutectic salt pads distributed between the joists of the upper level platform, and in the floor of the lower level. There is enough heat available from this source that in the worst month, January, sun, people, lights, and kitchen heat can supply 113% of the requirements for an average day. Thus, the back-up system does not have to cover catastrophic gaps, and an efficient fireplace would do the job, particularly because it could be integrated with the storage system so that the fire's heat could be released slowly, at a comfortable temperature.

In the warmer months the building can be kept comfortable by three methods. First: it can be opened up completely to catch breezes from any direction, and it has been calculated that a three mile per hour wind would be enough to keep the interior comfortably ventilated. Second: the metal structure which supports the fascia, and which enlarges the volume of the building and 'ties' the addition to the main building, also acts as a support for shading devices, which would be needed on the east and west in high summer. Finally: cafe fans can provide all the air movement needed for comfort an a still day.

As the roof is of mirrored glass on the upper surface it transmits less than 15% of the incident radiation. It thus provides a view out at the same time as it shades the interior. Shade, wind, and fans provide all the 'cooling' necessary, because heat build-up can be avoided completely by opening up the perimeter walls.

ROUTINE & 'PASSIVE' DESIGN RELATED

Before outlining what is essentially the calculative process of 'passive' design it is important to understand that design depends on a holistic, and definitely non-linear approach to problem solving. The design of a 'passive' building is not a matter of going through a process similar to the one described above, and then following it with the 'passive' cut. Ideally (although in reality time constraints have their effect), after each 'intuitive' decision a 'passive' evaluation would be made as outlined in the next section. This is not possible because the volume of calculation would be enormous.

Thus, what usually happens is that at some stage the design is evaluated on the basis of the 'passive' design method and, if the energy efficiency of the building leaves something to be desired, one makes changes by synthesizing, 'all at once', a number of decisions based on one or more of the Vitruvian triad, and others based on a knowledge of materials and an awareness (or feeling) for the effects these will have on efficiency. Then the calculation process is repeated, followed by 'intuitive' changes, then recalculation, until the desired level of efficiency is reached.

(The whole yearly calculation is not made at <u>every</u> stage. March is usually chosen as a representative month, acceptable in the case of a building with southern orientation. This short-cut was made in the case of the example in this chapter in spite of the fact that the orientation was definitely not south, and also in spite of the fact that the contribution from the sun in March was always above the seasonal contribution. But once the difference was known it was possible to allow for it in subsequent calculations.)

The bulky set of calculations in Appendix 2 is the result of the <u>penultimate</u> design. Certain minor changes were made after this using 'intuitive' approaches, but with an awareness that these changes would have minimal (probably positive) effects on efficiency.

A 'PASSIVE' DESIGN METHOD

The modified 'passive' design method presented here is an abstraction of a more holistic design approach. This method, however, deals only with thermal comfort, although total comfort is not simply a function of temperature. It is a complicated interaction of a number of impacts, among which are light levels, glare, color, and texture.

The method of measuring solar gain used in this design is a modification of one developed by Timothy Johnson (Department of Architecture, MIT), primarily for buildings which depend on south facing glazing for solar collection. The purpose of this modification is to enable one to account for multiple glazing orientations, & is dependent on a series of corrections (each of which could be further refined).

It depends on the use of programs for the Texas Instruments' TI-59 programmable calculator, programs developed by Tim Johnson, and by Cris Benton, Stephen Hale, and Jim Rosen (students in the Department of Architecture at MIT).

SUMMARY:

This method is essentially a measurement of the solar gain on an average day in each month, with checks for overheating on clear days in critical months.

i Clear day radiation is calculated to evaluate overheating, and to develop transmission factors for the glazing system.

ii Overheating is calculated for critical months, when solar gains could be rendered useless by the necessity to ventilate if sufficient storage is not designed into the building.

iii Corrections are made to reflected ground radiation figures, to account for radiation reflected through glazing which does not face south. It is an important correction with other orientations because, if it is not made, solar gain will be overstated.

iv Average daily radiation is calculated to find the amount of useable solar gain one might expect in an average year.

v Contributions from solar gain are finally compared to heat needs to evaluate the thermal efficiency of the design.

DETAIL:

i <u>Clear Day Radiation & Transmission Factors.</u>

Using Cris Benton's 'Solar Angles & Radiation' program, the clear day beam (i.e., direct) and diffuse radiation is calculated in two forms; radiation incident on the outside of the glass, and radiation finally transmitted.

Transission factors are developed by dividing transmitted radiation by incident radiation.

example 1

TRANSMITTED CLEAR DAY RADIATION & TRANSMISSION FACTORS

ORIENTATION ANGLE	BEAM			DIFFUSE		
	TRANS*	INCID¢	FACTOR#	TRANS*	INCID¢	FACTOR#
0	731.5	1216.9	.601	144.5	237.6	.608
-35	673.3	1110.3	.606	"	"	"
-90	428.1	690.1	.620	"	"	"
-105	315.8	528.5	.598	"	"	"
-135	94.4	199.6	.473	"	"	"
-165	2.2	13.3	.165	"	"	"
ROOF	183.0	1248.1	.147	25.6	174.1	.147

*Transmitted

¢Incident

#Transmission Factor

ii Actual Ground Reflected Radiation.

This refinement is performed by using data from Jim Rosen's 'Average Daily Radiation' program.

The calculation proceeds as follows:

a. select the orientation with highest beam radiation

b. find ratio between beam & diffuse at this orientation

example 2

Ratio of Beam to Diffuse

	Radiation	Ratio
Highest Average Day Beam	645.2	.743
Average Day Diffuse	222.8	.257
Totals	868.0	1.000

c. apply these ratios to the radiation reflected from ground to break it into beam & diffuse components

example 3

Beam & Diffuse Components
(at highest Beam orientation)

	Reflected		Ratio		Radiation
Beam component	106.7	x	.743	=	79.3
Diffuse component			.257	=	27.4
			1.000		106.7

d. calculate 'beam factors' to relate beam radiation at each orientation to the level at the orientation where it is highest

example 4

'Beam Factors'

Orientation Angle	Beam Radiation	Beam Factor
0	645.2	1.000
-35	619.4	.960
-90	430.1	.667
-105	309,2	.479

e. apply these factors to the beam components found in (c.) to find the actual beam component at each orientation

example 5

Beam Component of Ground Reflected Radiation

Orientation Angle	Highest Beam Component	Beam Factor	Beam Component at Angle
0	79.3	1.000	79.3
-35		.960	76.1
-90		.667	52.9
-105		.479	38.0

f. add this to the diffuse component found in (c.) (the same at each orientation) to get actual reflected radiation at each orientation

example 6

Actual Reflected Radiation (from ground)

Orientation Angle	Beam Component	Diffuse Component	Actual Reflected
0	79.3	27.4	106.7
-35	76.1	27.4	103.5
-90	52.9	27.4	80.3
-105	38.0	27.4	65.4
-135	-	27.4	27.4
-165	-	27.4	27.4

iii Overheating in Critical Months

Overheating is dependent on (among other things) the area of south facing glass and the mass of the heat storage medium. In this building there is little south facing glass, which can be taken into account by the use of a rough correcting factor outlined below;

a. using 'Solar Angles & Radiation' figures calculate the total clear day radiation collected by the whole building, (*i.e.*, by multiplying transmitted radiation at each orientation by the glass area and summing the results)

b. to find the area of south facing glass which would provide the same amount of radiation, divide the non-south radiation by the radiation per sq. ft. on south facing glass

example 7

Equivalent 'South' Glazing

Total Clear Day Transmitted Radiation	1,281,616	BTU
- Radiation from South Glass	481,800	
	799,816	
BTU/SQ. FT. on South glass	876	
Non-south Equivalent (799,816/876)=	913	Sq. Ft.
+ Real South Glass	550	
Equivalent 'South' Glazing	1463	

Stephen Hale's 'Niles" program uses this figure to calculate the equilibrium temperature of the building, and the amplitude (or temperature swing) for both radiative and convective connections between the solar gain and the storage location.

A rough estimation of the unventilated noon temperature can be made by adding 2/3 of the amplitude to the equilibrium temperature (since the program assumes that temperature peaks at 3.00 pm.).

If this figure is too high, design changes are then made (eg., reduce glazing, increase storage, change form, etc.).

(In this design fans go on at noon, and ventilation removes any additional heat build-up in winter. In summer, the cafe fans and the open window-walls ensure that the interior temperature will be slightly above the exterior temperature, a situation offset by the cooling sensation of the passage of air.)

iv Average Daily Radiation Transmitted

Take average daily radiation corrected for reflected radiation from step ii. for each orientation. Multiply this figure by the transmission factors from step i. This figure is the amount of radiation per sq. ft. transmitted at each orientation.

This figure is multiplied by the glass area at the particular orientation. The results of this multiplication are then summed to give a total daily transmitted radiation figure for the whole building.

When this total is multiplied by the days in the month a total heat gain for the month is available.

(This complete calculation is given in the following example.)

example 8

Average Daily Radiation Transmitted

ORIENTATION		INCIDENT RADIATION	TRANSMIS FACTOR	TRANSMITTED RADIATION	GLASS AREA	TOTAL RAD'N TRANSMITTED
0	BEAM	645.2	.601	387.8		
	DIFF	228.8	.608	139.1		
	REFL	106.7	.608	64.9		
	TOTAL			591.8	550	325,490
-35	BEAM	619.4	.606	408.8		
	DIFF	228.8	.608	139.1		
	REFL	103.5	.608	62.9		
	TOTAL			610.8	330	201,564
-90	BEAM	430.1	.620	266.7		
	DIFF	228.8	.608	139.1		
	REFL	80.3	.608	48.8		
	TOTAL			454.6	105	47,733
-105	BEAM	309.2	.598	184.9		
	DIFF	228.8	.608	139.1		
	REFL	65.4	.608	39.8		
	TOTAL			363.8	280	101,864
-135	BEAM	-	.473	-		
	DIFF	228.8	.608	139.1		
	REFL	27.4	.608	16.7		
	TOTAL			155.8	280	43,624
-165	BEAM	-	.165	-		
	DIFF	228.8	.608	139.1		
	REFL	27.4	.608	16.7		
	TOTAL			155.8	910	141,778
ROOF	BEAM	578.5	.147	85.1		
	DIFF	444.3	.147	65.3		
	REFL	0.7	.147	0.1		
	TOTAL			150.5	905	136,202
						998,255

Average Monthly Radiation Transmitted (Total heat gain)

998,255 x 31 = 30,945,905 BTU/MARCH

v. Monthly & Seasonal Heating Fractions

The 'Bin Data' method is used to calculate these percentages. This method is a refinement of the normal 'Degree Day' method, which assumes that all buildings reach a balance with the external environment at 65^{o}F. This is not true; the balance point is a function of the resistence of the building's skin to heat loss, the temperature of the interior, and the internal gains from people, lights, etc..

As the balance point is lowered (because of better insulation, higher internal gains, or lower thermostat levels), the impact of the external environment is also lowered. That is; the 'degree day' figure is modified to show a lower value than that which would have resulted from the assumption that the balance point is always 65^{o}F.

Tim Johnson's 'Bin Data' program uses this method to calculate the monthly heat load. The solar contribution to this load can be divided by the load* itself to give a Net Solar Fraction. This does not, however, account for the contribution from people and lights, which can be corrected by adding this contribution# to the load as the denominator in the division to give a Gross Solar Fraction.

example 9

Solar Fractions

March load (from 'Bin Data' program) 32.7 mill BTU's

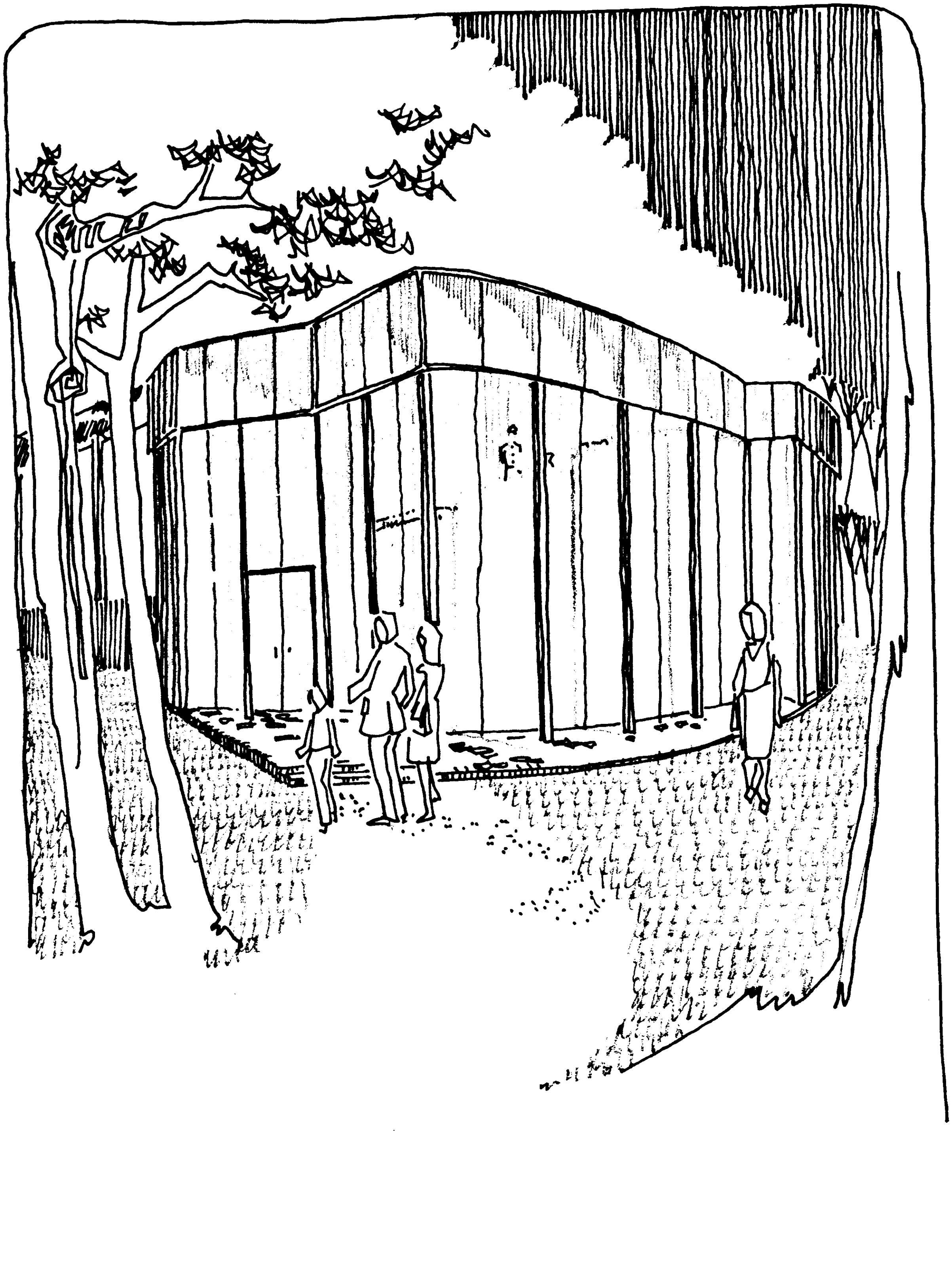
NET Solar Fraction: $30.9/32.7^{*} = 94.7\%$

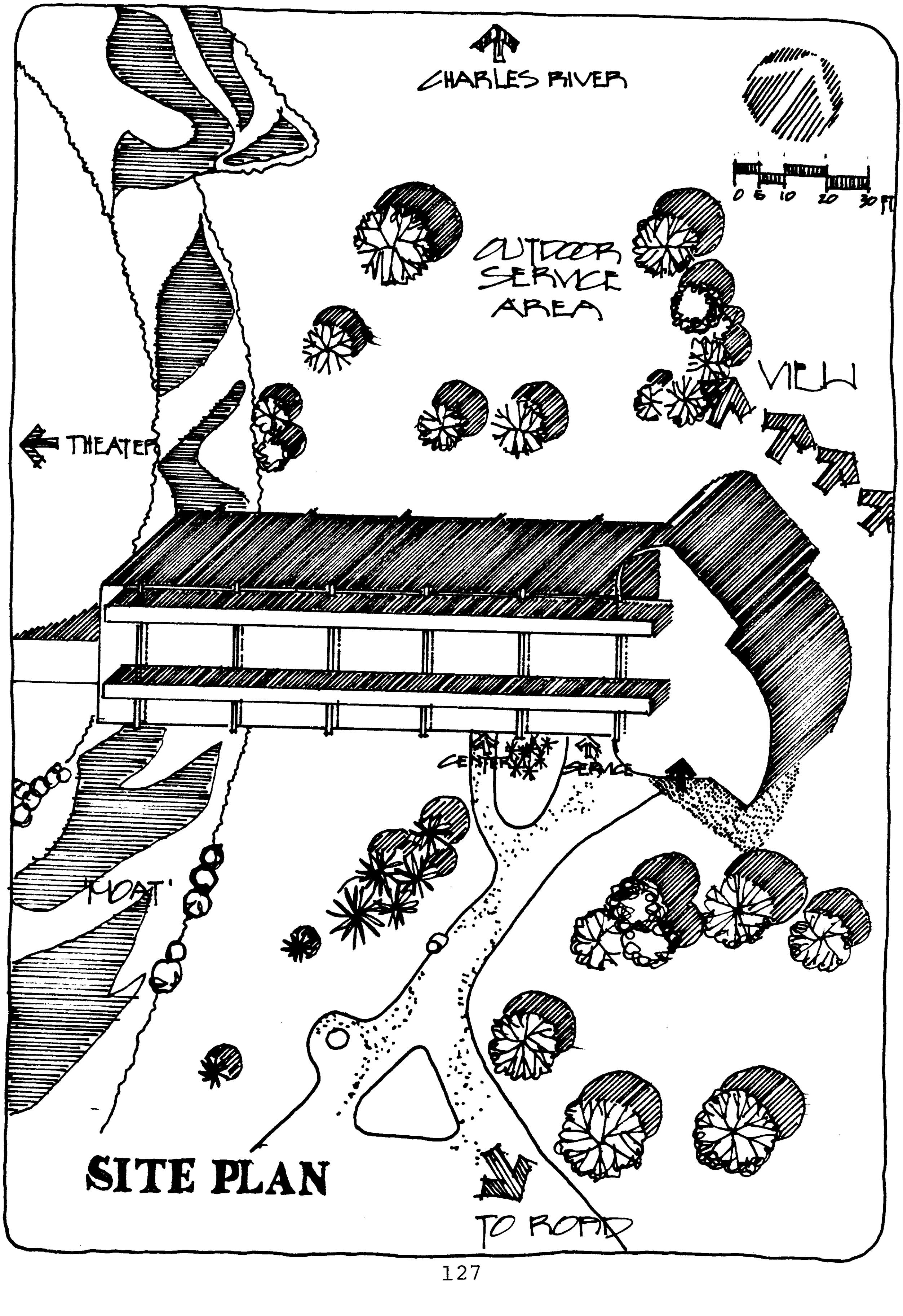
GROSS Solar Fraction: $30.9/(32.7 + 6.4^{\#}) = 79.2\%$

DESIGN PRESENTATION

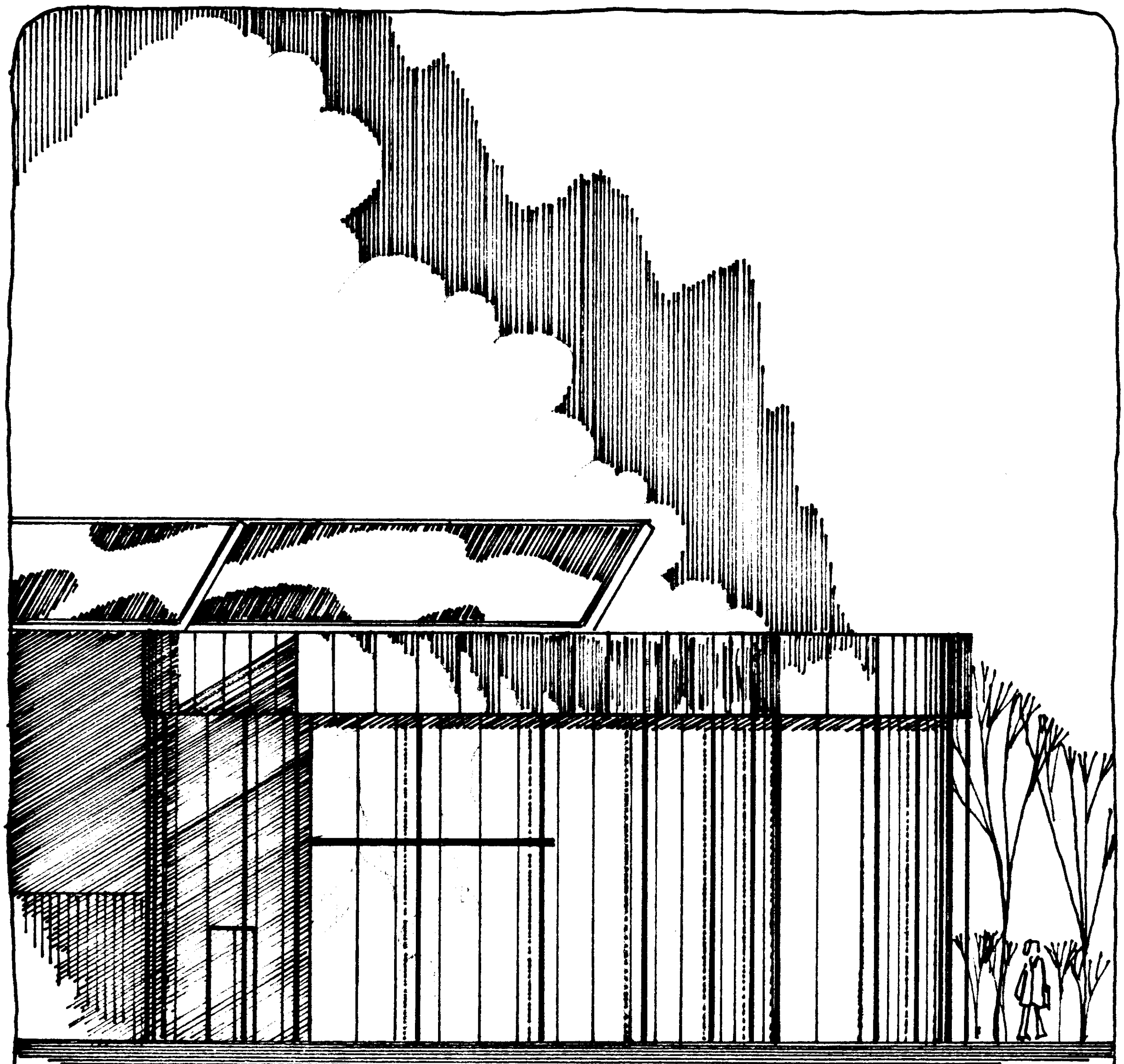
The following conceptual drawings and tables are for presentation before the detailed design stage is begun.

The interaction of the constraints outlined earlier would be continued, refined by structural detailing which would be likely to affect form. It is, therefore, possible that demands of structure could affect the energy efficiency of the building (as well as the interplay of function with everything else). If so, recalculation, followed by more changes, wolul continue, with a final calculation after all the details had been resolved.




CHARLES RIVER
0 5 10 20 30 FT
OUTDOOR SERVICE AREA
VIEW
THEATER
CENTER
SERVICE
'MOAT'
TO ROAD

SITE PLAN



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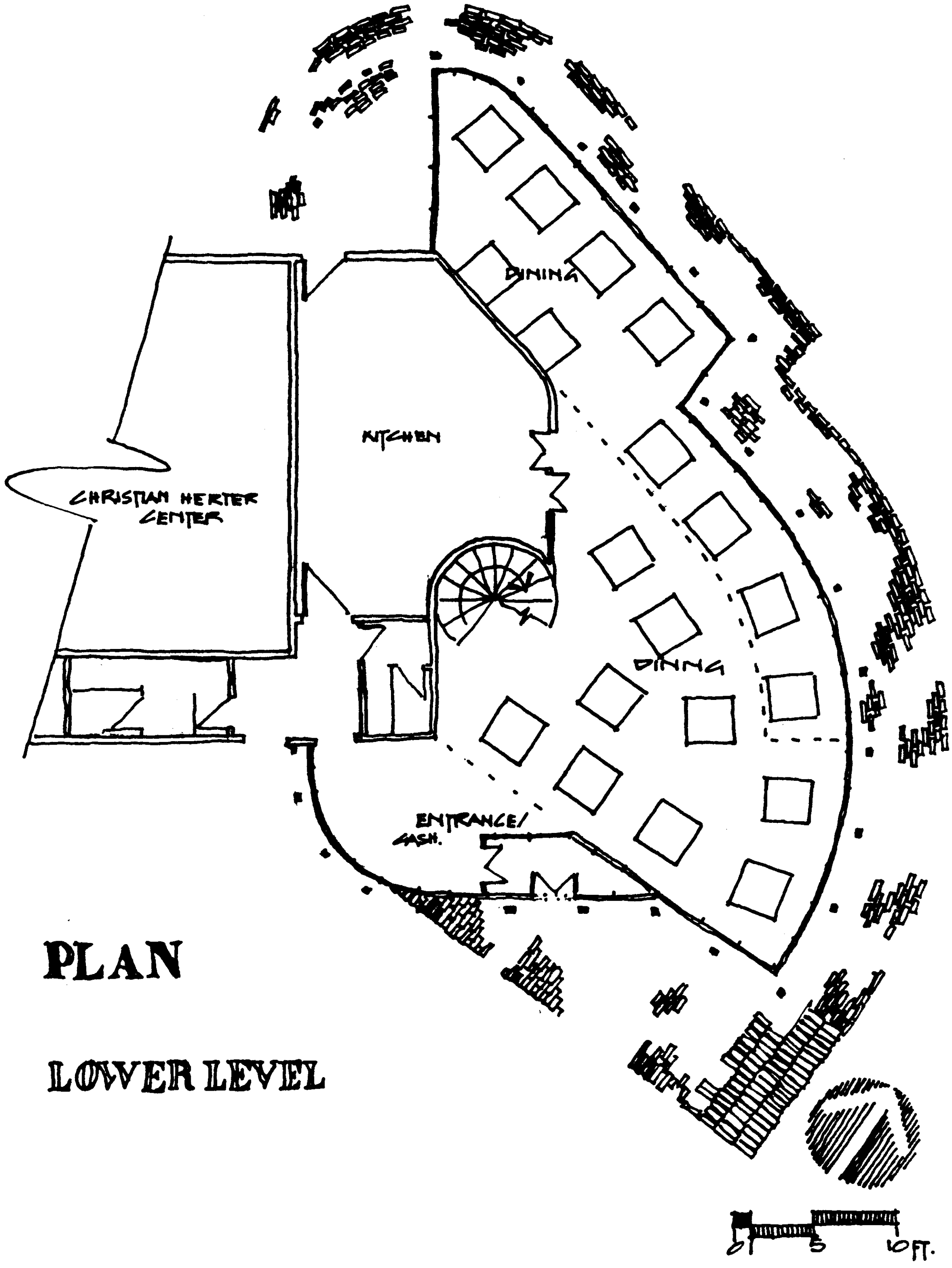
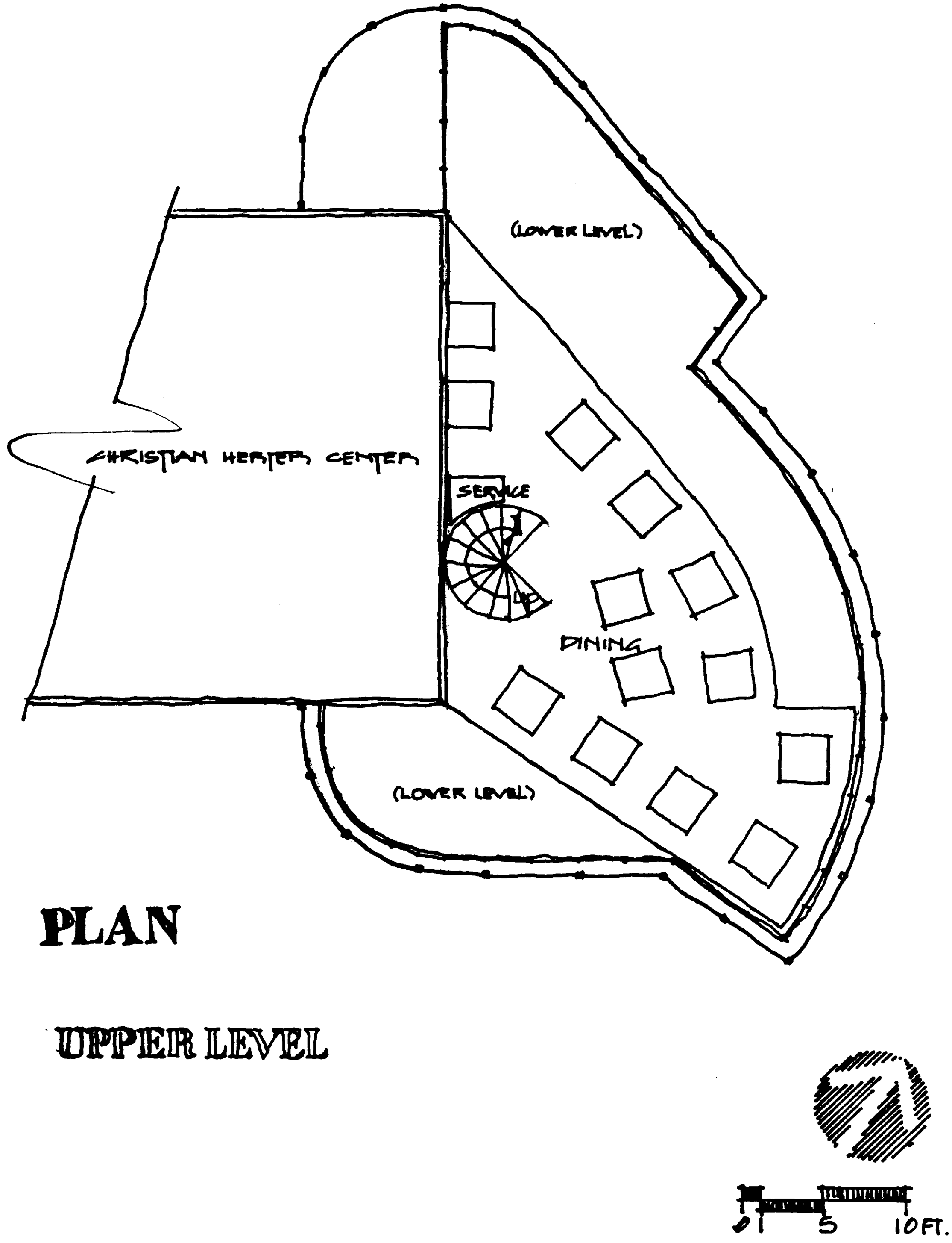


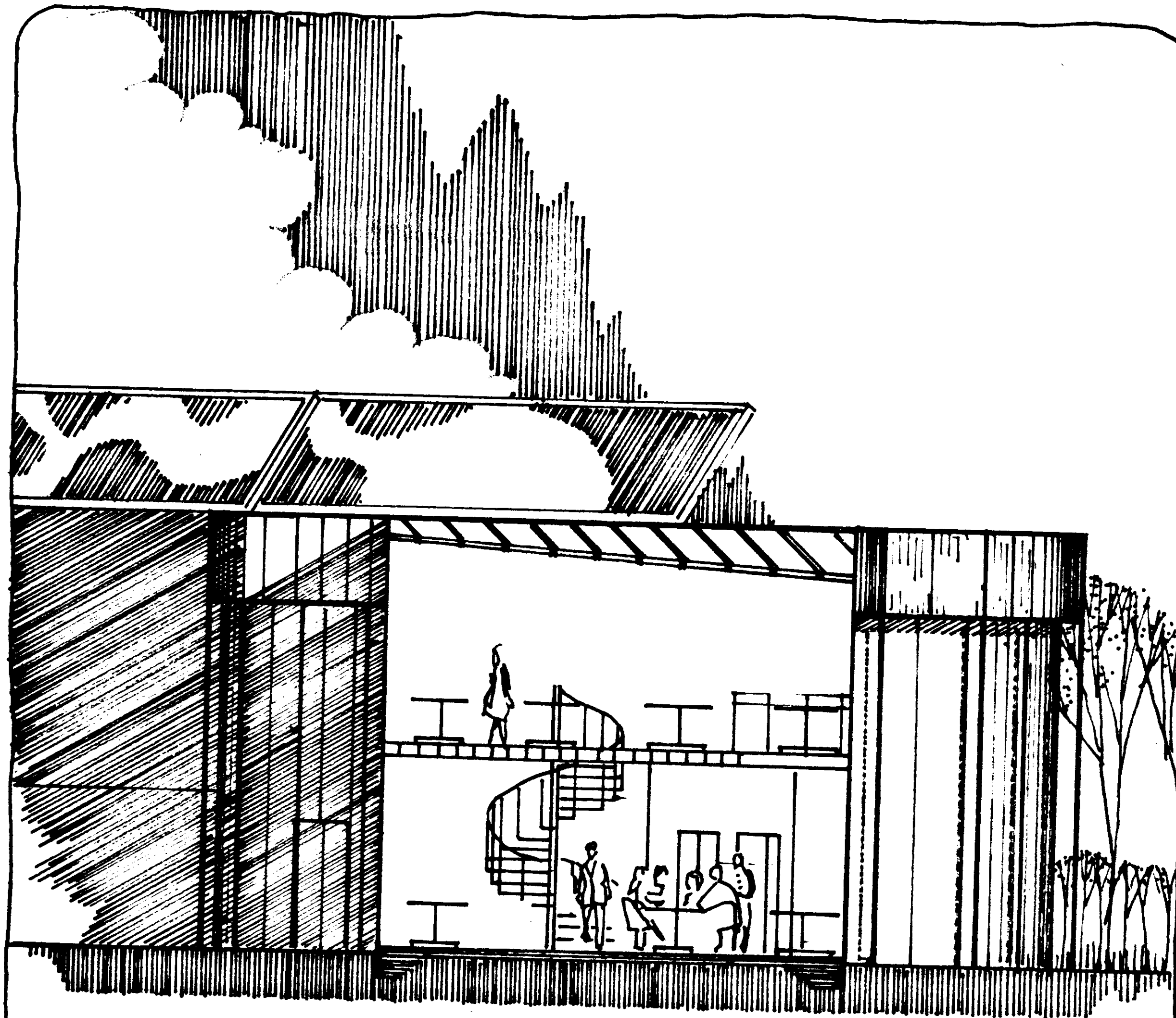
PLAN

LOWER LEVEL

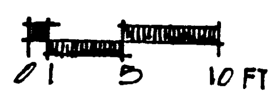


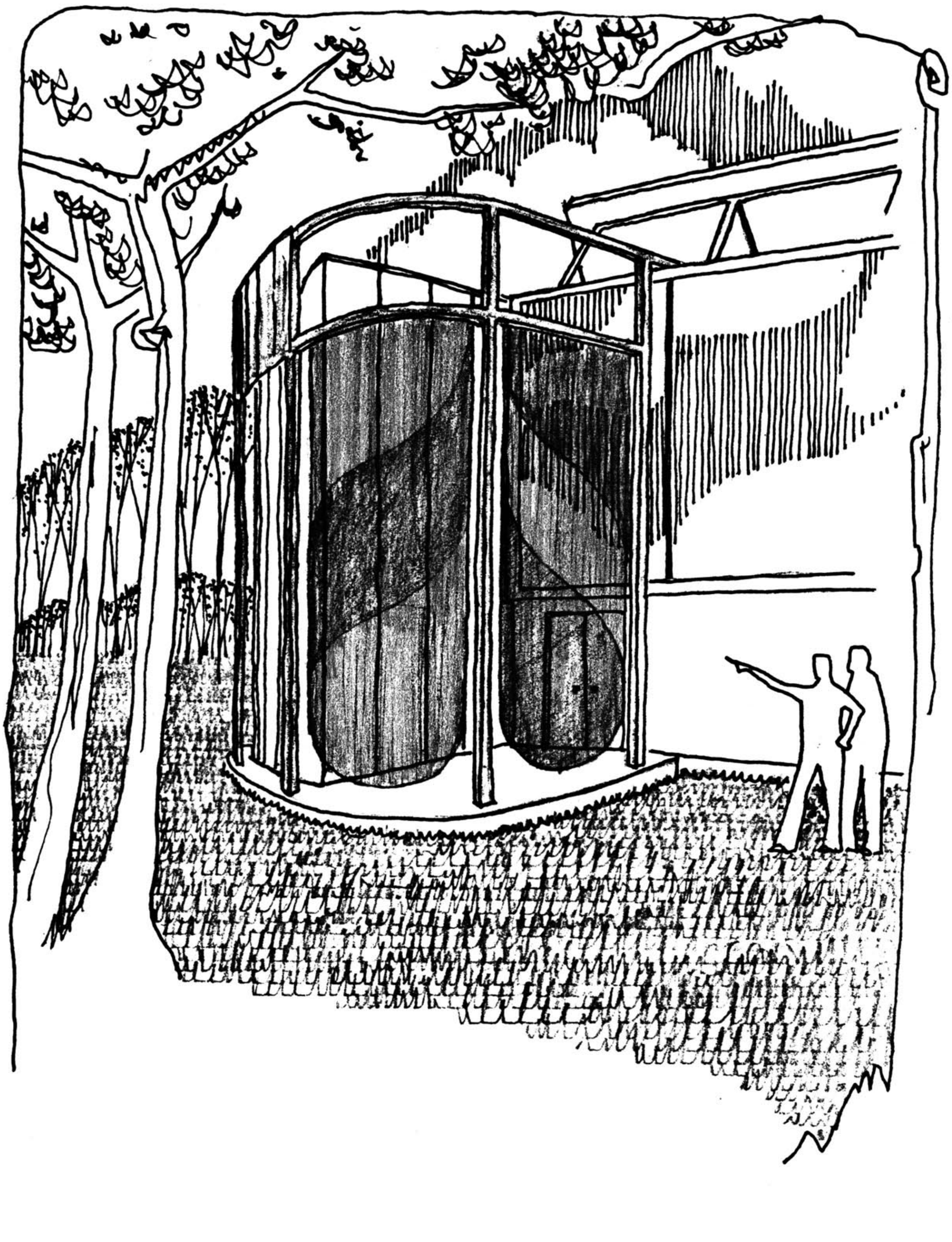
PLAN

UPPER LEVEL



SECTION





SOLAR HEATING FRACTIONS:

NET

OCTOBER	100%
NOVEMBER	93
DECEMBER	45
JANUARY	46
FEBRUARY	58
MARCH	95
APRIL	100
MAY	100
SEASON	68

GROSS

OCTOBER	100
NOVEMBER	72
DECEMBER	39
JANUARY	42
FEBRUARY	51
MARCH	79
APRIL	100
MAY	100
SEASON	62

WITH RECYCLED KITCHEN HEAT *

OCTOBER	100
NOVEMBER	100
DECEMBER	100
JANUARY	96
FEBRUARY	100
MARCH	100
APRIL	100
MAY	100
SEASON	99

*USING TWO HEAT EXCHANGERS IN SEQUENCE

CONCLUSION

The program for this building called for energy conserving features, and the final design was able to achieve a Net Solar Fraction of 68%, and a Gross Solar Fraction of 62%, for the entire heating season. Net Fraction ranged from 45% in December to 100% in April, May, and October.

By using recycled kitchen heat (from two sequential heat exchangers) practically 100% of the heating needs for an average heating season is possible, meaning that the backup system does not have to be a major mechanical addition, but can be an efficient fireplace.

This sort of efficiency is only possible to design for when the designer has a capability to work with technical information. But the integration of technology with other aspects of the design process is only possible when the 'technician' is trained in design. These two aspects of design are integral, and 'passive' technology cannot be handled as a 'second step' which is the responsibility of the 'passive expert'. It is the responsibility of the architect/designer.

It is hard to say what the design for this building would have been like if the constraint of energy efficiency had not been the governing constraint, active from the beginning of the design process. What is important is that this observation can only be made <u>because</u> a 'passive' design method was used.

It is most unlikely that one would have chosen such a perverse material as glass. The major problem would not have been heat loss, which would have been handled routinely by replacing the heat mechanically. Summer cooling would have been more of a constraint. Because in non-energy conscious design summer comfort was treated as a function of temperature alone, ventilation would not have been considered. This would have meant a sealed structure. In an all glass building, without the benefit of the heat capacity of Sol-Ar-Tiles air conditioning would have been needed even in the heating season, and would have been prohibitively expensive.

About all that can be said about a design which was not governed by the energy constraint is that it would have been considerably different. Without an awareness of the existence of materials like Heat Mirror and Sol-Ar-Tiles, and <u>without the ability to calculate the effect of using them</u>, it would have been quite impossible to take the responsibility for the comfort of the users. Even if materials other than glass had been used, and heat storage had been real mass, the ability to calculate heat balance would have been necessary.

The design which resulted, while it would have been possible, given certain formal predilections on the part of the designer, would have been ridiculous because it would have demanded an exhorbitant expenditure on the installation and operation of an HVAC system, which (of course) would have been designed by a mechanical engineer.

CHAPTER 5

ELIMINATING OBSTACLES TO 'PASSIVE' SOLAR ENERGY

INTRODUCTION

The first task in this chapter is (having set forth the nature of the institutional arena in Chapters 1 and 2, and the general nature of architectural design in Chapter 3) to define the institutional nature of the architectural profession. Whether it is organizational (formal or informal), whether it is non-organizational (collectivity or social order), what its functional/compliance typology is, has a particular impact on the methods which can be used efficiently to accelerate the integration of 'passive' design into the routine of the profession.

The second task deals with those elements which make 'passive' design possible, yet do not fit in with the competence or disposition of most architects because they have been socialized into a role defined by different actions. These elements must be incorporated into the perception of the architect's role. By making use of the understanding of the institutional structure of the profession an evaluation of illustrative types of innovation acceleration programs for 'passive' solar energy will be made. Recommendations for their alteration (where necessary), and for their incorporation (where appropriate) into a procedure which will ensure an acceleration of their acceptance by architects will complete this second task.

THE ARCHITECT'S ROLE AND 'PASSIVE' DESIGN

'Passive' solar energy systems face a plethora of social barriers which continue to act as a felted mesh blocking the pathway to acceptance. Getting rid of one barrier is, because of this interactive relationship between it and others, difficult. But the other side of this coin is that, *if* one obstacle is effectively removed, there is a consequent weakening of the relationship between others. It is not, therefore, a matter of removing all of them one by one. As each falls, those that are left have less power to prevent change than they did when they lent strength to, and gained it from, others.

'Passive' faces a particularly important obstacle to acceptance right at the beginning of the pipeline, and when constriction occurs at this point there are no other outlets through which the flow of information can pass. 'Active' would have encountered the same barrier if it had been dependent on architects for its meaning/function attribution. But, because it was capable of being routinized at the level of a regular inter-professional interaction, the flow of information, when it could not be handled by an architect, passed through the mechanical engineer.

The fact that 'passive' is a uniquely architectural solution, which can only be dealt with by the integration of human comfort into the definition of _utilitas_, is not (as can be seen from the previous chapter) inconsequential for the designer who accepts this responsibility. It is not that those of us who do accept it become 'functional rationalists'. In fact, in the design process for the restaurant, I made a point of trying to slaughter one sacred cow, the belief that energy conscious design is always obviously energy conscious design.

The design process may well have started with a 'first cut' through _venustas_ for this reason, but that aspect of _utilitas_ which had to do with comfort was omnipresent from then on, and was rendered meaningful (_i.e._ integrated with _firmitas_ and _venustas_) by means of an involvement with mathematics _through the use of a set of computer programs_, a method of involvement which is not part of the perception of the necessarily 'correct actions' which define _architect_. Fellow architects, who watched the process from the position of 'real architects', were often cynical about 'number crunching', or sarcastic about 'passive' as a passing fad. My TI-59 programmable calculator became so much a symbol of my 'incorrect actions' that I began to keep it out of sight, and at this point became aware of the socializing to which I had been subject. Not only is the technical process difficult to learn, its command is part of a set of actions which indicate 'non-architect', rather than 'architect-plus-something-else'.

In a few cases some were ready to admit to an inadequacy insofar as command over technical information was concerned, which they agreed was unfortunate because they <u>were</u> interested in 'passive'. But the very process of watching someone involved in a process which appeared to be so difficult, or distasteful, or both, was enough to discourage further interest.

There is <u>no</u> way around the technical aspect of passive design. In most parts of the country winter is harsh enough to necessitate fairly rigorous calculation if the comfort of a building's occupants is to be maintained. It is not simply a matter of doing all the right things as far as conservation is concerned, putting in windows to gain sunlight, and some storage facilities, and then relying on a back-up system. The size of the back-up system is dependent on the success of the 'passive design', as is the type of this system. The question of whether a mechanical engineer will be needed depends on the size of the building, but even if one is, the 'passive' aspect of the design will be totally out of his control.

Thus, if 'passive' solar energy is considered to be a workable alternative energy source for a reduced dependence on regular energy supplies, it must be integrated into the routine of 'architecture' before it can be integrated into the routine of society. Dependence on peer pressure has created very few architects who are capable of 'passive' design beyond the 'rules of thumb' level, many of whom are still <u>morally</u> committed to conservation . While most change has to follow this path at its beginning, before it can be truly integrated it must move beyond it.

If energy conscious design can find its place at all levels of society it will have to be routinized by architects who are concerned with form, or with broadly defined function. If these individuals continue to perceive conservation as being inimical to their major concerns it will be rejected. For these architects 'passive' must be seen as something that does not override these interests, and it must be seen as part of those actions which, if performed, contribute to the perception of the performer as an architect (rather than not-contribute to a perception of him as a non-architect).

INSTITUTIONAL THEORY SUMMARIZED

It will help at this stage to summarize some of the more important features of the chapter on institutional analysis and institutional theory.

An institution is an abstract social entity which is perceived to manifest shared meaning structures, and in relation to which the meaning structures of those who do, or do not, share them are assessed.

The institutional arena (all those entities which are institutions) comprises certain groups of individuals who form organizations and others forming entities which are not organized (non-organizations).

Organizations can have a formal structure, where those in a power position (higher order participants) have the ability to direct subordinates (lower order participants) to perform certain actions. The subordinates, however, also learn from their peers certain correct actions for their own interaction. These two forms of information transferral interact. When the organization is formal there is a hierarchy imposed by the higher order participants, and accepted by all. In an informal organization the hierarchical quality exists, but it is an expression of an evaluation by all participants, and not imposed.

Membership in organizations can also be institutionalized, so that the qualities expected of a member become abstracted into a set of values, or a meaning or function, against which others can be assessed.

Non-organizations can be either collectivities (an institutional entity with participants characterized by a a common quality or interest) or social orders (a societal disposition without specified members, but which exists because of individuals' disposition to contribute to, or participate in, it).

Both collectivities and social orders have no hierarchical structure. In certain cases participants need not even be aware of participation.

Individuals or persons can be institutions when certain aspects of their personalities are abstracted by others, and they become entities which manifest values, or meaning and function, to those others.

Collectivities and social orders are not organized bodies, and do not, therefore, have a hierarchy accepted by all their participants. This does not mean, however, that there are no higher order participants. But, in spite of this fact, the imposition of directives which is possible in an organization is not possible elsewhere. What does happen is that certain individuals become accepted (through the process of iterative perception) as embodying the common interest or condition of the participants in a collectivity, or the disposition of participants in a social order. In this way, without the superior/subordinate relationship which is essential to organizations, non-organizations can have higher order participants.

Institutions, therefore, can be treated as being analogous to organizations. They are basically groupings of 'line' personnel because almost all participants are active at the interface between the institution and the environment. There is, if any, only the most minimal staff, or bureaucratic, support.

Because of the freedom of participation in non-organizations, it is impossible for any participant to exert coercion. Individuals may reject the values implied by the institution, but unless they are forced to accept membership in it as an organization, they do not have to participate institutionally.

Thus non-organizational institutions tend to be 'line' entities in which lower order participants tend to comply with the 'imperative' implied in the example of the higher order participant on a normative/moral basis, or (at times) on a remunerative/calculative basis.

'ARCHITECTURE' AS AN INSTITUTION

The architectural profession is recognizable at all levels of the institutional arena, except that of the informal organization. It expresses itself through _formal organizations_ (_eg_. the American Institute of Architects, the architectural firm), _collectivities_ (_eg_. architects, architecture students), and through the _members_ of formal organizations and _persons_ who belong to collectivities. It is even recognizable as a contributor to _social orders_ such as 'good taste', 'beauty', _&c_..

It exists, institutionally, at four levels of perception, those of:

i observer
ii student
iii teacher
iv practicing architect.

Insofar as the _observer_ does not have a high level of either involvement or commitment he may be considered an outsider, and his perception of the role of architect has only a minimal impact on the perception of insiders.

(Although the perception of the student is formed as an observer, through a process of iteration in which the others take part, his involvement in the process is limited to one which contributes almost nothing to the perception of insiders.)

'Architects', for the purposes of this study, includes students, teachers, and practicing architects. Students and teachers, however, not only have a perception of the 'correct actions' necessary for the role of architects. They also have a perception of their own roles which are (in their relation to one another) more formally delineated than that of the architect _per se_.

While there _are_ certain formal organizations which represent the profession (_eg_. the A.I.A.), and others which regulate it (eg. state licencing boards) they have minimal control over the individual architect compared to the control which really formal organizations like trades unions have over their members. Practicing architects are not participants in a formal organization. Although there are certain regulated activities which architects are expected to perform (or not perform), regulation has its impact at the frontiers of architectural experience, and barely impinges perceptually on one's conception of role.

The architectural profession, inspite of the various formal organizations to which each architect belongs, is a collectivity, an indistinct entity with members characterized by a condition or quality of collective focus. There is, of course, a fairly distinct division between registered architects and the rest of the world. But, if the group 'architects' includes recent graduates and students, as well as teachers, this distinction begins to break down. The absence of organizational qualities which this implies leads one to infer a minimal influence of higher order participants, in a group which is almost all line (supported by a relatively invisible staff in organizations like the A.I.A.)

An institutional view of the profession in this way, as a non-organization, and a collectivity, has certain implications on the choice of methods one might employ to accelerate the integration of an innovation like 'passive' design by the members of the profession. The involvement of the architect <u>in the profession</u> is more akin to a normative/moral relationship among participants, with a certain amount of remuneration/calculation, although this latter quality is more descriptive of the relationship between principals and employees in an architectural firm. If the profession were a formal organization one could concentrate on gaining the support of the leading representatives of the organization. The imperatives of these higher order participants would react iteratively with peer pressure from below, until a congruence of purposes which was close to the intentions of the leaders was attained.

In non-organizations. however, although there is an unmistakeable influence of the imperative, the imperative is subordinate to peer pres-ure. Aside from this, in non-organizations the compliance structure, insofar as higher order participants do exist, is almost purely normative /moral, or remunerative/calculative. The absence of formal or informal organizational qualities implies a minimal influence of these higher order participants, because the entity is almost all 'line' (supported by a relatively invisible 'staff', in organizations like the AIA.

A collectivity, however, does have some higher order participants. They may be viewed by other participants as only 'first among equals', but this does not mean that they are without influence, or that peer pressure is the only mechanic of change. There _are_ leaders in the profession, although these leaders will be different for each architect. They are not necessarily the 'stars' of the profession either, because if one defined one's role in terms of the most successful one would (unless one were one of them) be definitionally incapable of performing all of these actions.

The influence of higher order participants is, at the same time, part of the process of the actual 'creation' of higher order participants. To explain: if those who are architects perform actions which are _seen_ to be performed, then these actions, by virtue of the visible position of the performer, become 'correct actions'. And, by virtue of this visibility, the performer becomes a higher order participant. The superior/subordinate relationship is defineable at many levels at once in a non-organization. The explicit definition of who is a higher order participant in a collectivity such as a nation-wide group of professionals is impossible. For example, one's employer is a superior, but if one perceives oneself as a better designer, then he is a subordinate, and an architect renowned for his school designs may be of no importance to a hospital designer.

By being raised to a position of visibility any architects become higher order participants, and if this visibility includes an ability to incorporate a responsibility for human comfort into utilitas (and the attendant technical command) then these qualities become, in some way, part of those which are correct for any architect.

In effect that means that if 'passive' solar energy is important enough to those whose function it is to limit national expenditure on energy (and conservation gets much of its validity economically, not morally), then a program directed at exhibiting architects who have the ability to design in this way will contribute considerably to the elimination of a major professional barrier to the integration of 'passive' solar energy into the routine of design.

REFINEMENT OF PROGRAMS

Unfortunately, many of the programs which have been been presented to the profession have not differentiated between the methods of promoting 'active' and promoting 'passive'. (This is not an attempt to suggest that one is better than the other. In fact, any approach which considers both as having a place in design improves one's ability to limit the impacts of the constraints of the physical environment.) The point is that, because these two approaches are so completely different in their impact on the profession, and because the impact of the profession on each is so completely different, it is most unlikely that a program which will remove barriers to the routinization of 'active' solar energy will have the same effect for 'passive'.

Aside from this, many of the programs have been directed at the effect they would have on those outside the profession, as demonstration projects to the market using the developer as the ganglion synthesizing all the obstacles to routinization. As far as the design professionals are concerned, most of these programs have been directed at professionals who are already able to design solar, and have been sermons to the converted.

Any program directed at routinizing 'passive' design into the vocabulary of the architectural profession should do the following:

i define 'passive' design

ii demonstrate and reinforce the point that capability in 'passive' design can contribute to professional fulfillment, and is not inimical to structural, functional, or aesthetic design approaches

iii contribute to the education of students and to the re-education of practitioners.

i Definition

The architectural profession as a collectivity tends towards a normative/moral relationship among its participants. Therefore, because normative/moral interaction depends entirely upon the clarity of definition, definition is vital. There is no superior to rule on the correctness of actions. Thus, the entire discussion in Chapter 3 in which 'active' and 'passive' were distinguished in terms of their meanings insofar as they bear on professional activities, implies that for the redefinition of role publicity is important. The recent emphasis on 'passive' in architectural journals has been particularly effective here.

Many of the demonstrations programs which have taken place have been directed at the exhibition of 'solar' technology without differentiating between 'active', 'passive', and 'hybrid'. The National Solar Heating and Cooling Demonstration Program (SHAC) has, for example, distributed grants to developers and professionals on the basis of the cost of the solar energy system.

In the recent 'passive' cycle this has raised the problem of delineating exactly what is part of the normal process of design, and what is part of the 'passive' system. The <u>ideal</u> passive system (so ideal as to be unattainable) would not only not be separable from the rest of the design, it would be so integral to the whole design that it would not cost any more. This is an unreachable perfection, but the point is that the approach which the SHAC program has used is counter-productive. For a developer to get the maximum financial benefit from the SHAC grants (as the program is presently constituted) it is better to have the most expensive system possible.

Perhaps a better method of getting this aspect of definition of 'passive' across would be to grant those selected a sum approaching the maximum amount given for a building of the size and type submitted, stating explicitly that the difference between the grant and the actual cost of the 'passive' system is a premium for efficient design. One of the criteria for selection, stated as such, should be this sort of economic evaluation of the synthesis of the Vitruvian triad, energy efficiency, and cost, so that the designer can understand the definition of 'passive' as a process of integration,and not as a process of addition.

ii Demonstration and Reinforcement:

In highly line organizations the power of the imperative, in the form of directives issued by superiors, supported by staff personnel, is non-existent. Thus demonstration becomes an important mechanism for the dissemination of information on 'correct actions'.
The creation of a position which is analogical to that of

the higher order participant is dependent on the visibility of people who perform these 'correct actions' well. People who can exhibit what these actions are, and how they are done, provide the role models necessary for peers to begin to perform new actions deemed appropriate in a collectivity.

Demonstration programs ensure the visibility of these role models, and of actions the correctnes of which one wishes to reinforce.

There is, however, a need for some iteration between two different design positions at this point. Energy conscious design cannor, and should not, be supported on the basis of energy efficiency alone. It is, for this reason, time for selection committees in programs such as SHAC to consider venustas and utilitas explicitly, and to require good design as much as they require energy efficiency. Many of the designs selected so far have been outstanding, but many have left 'non-solar' architects convinced that solar design does not help define 'good architect'.

Designs presented in programs developed in conjunction with the AIA are usually aesthetically more successful than those presented by DOE and HUD alone. (Compare the early SHAC Project Data Summaries with that from the third cycle.)

Evaluation on the basis of energy efficiency alone, while easier because it can be based on quantifiable data, is counter productive because it dismisses the very challenge that can attract architects, the action that defines their role.

Not to consider design is to suggest to any architect that his special capability is unimportant to good 'passive' design.

iii Education of Students and Practitioners:

The essence of a collectivity is the process of socialization. The acceptance of a normative/moral context is the result of one's involvement in this process. The acceptance of norms is a matter of belief, acquired only by an ability to know the meaning structures of the institution. In the architectural profession this is, to a large extent, accomplished through education. Education is explicitly a socialization process, specially so with architecture and its master-apprentice-studio tradition of teaching.

a. Students

As the education of students is in the hands of the teachers of the profession, an important gap to be filled is the incorporation of energy conscious principles into design education. One may assume that one of the effects of the previous two points will provide enough redefinition of role for students to expect to learn these principles.

There is, currently, a program sponsored by the Department of Energy, and presented jointly by the A.I.A. Research Corporation and the Association of Collegiate Schools of Architecture, which is directed at this problem. It "is designed to serve as a gathering place for architectural educators who wish to involve themselves in aspects of energy and design". (Appendix 3.) The program, the annual Summer Institute on Energy and Design, is to be held, this year,at M.I.T. from 12 to 17 August., and will be held each year at a different school.

An expansion of this program (because there is a selection process) could be directed at the varying levels of technical qualification, increasing the number of educators capable of integrating 'passive' design into their teaching methods.

b. Practitioners

A similar program should be directed at design professionals. These people are becoming increasingly aware of the place of 'passive' in the role of the architect, a situation which would be improved by the implementation of the first two points of the suggested program. However, the technical command necessary cannot be learned from articles in professional journals, which for many is all the information available right now. Even though these articles are contributing much to the process of redefinition of role, they are only touching the surface when it comes to the process of re-education.

A program making use of the increasing number of educators capable of teaching the elements of energy conscious design should be held in architectural schools throughout the country to train professionals. And as the 'Summer Institute' program continues the number of teachers available will increase.

Ideally these 'institutes' for the re-education of professionals should be held in more than one school each year. The success of any program of redefinition (illustrated by the increasing interest in the articles in the AIA Journal on 'passive'), and demonstration and reinforcement will increase the number of professionals who want re-education.

Professional 'institutes' could be held in every school where there is no full-time summer semester, at a frequency which would depend on the rate of success of those aspects of the program which are directed at integrating energy conscious design into a new perception of the role of the architect.

CONCLUSION

There is a certain peripatetic quality to this study which was inevitable. The broad scale of the analysis of the theory of organizations and institutions defined a field far broader, in every dimension, than the architectural profession. Yet, the building industry, of which the profession is but one part, presents a mesh of institutional barriers to any innovation which can only be understood within the context of the whole institutional arena.

It is obvious that there are many barriers to an innovation like 'passive' solar energy, and this work was a search for one of them. There was no attempt to use institutional theory to support a previously developed hypothesis. Rather, the feeling that there was one particularly important problem at the beginning of the pipeline seemed to call for an understanding of the total environment into which 'passive' was being introduced.

It boiled down to this: Things get done primarily because someindividuals want them to be done, but cannot get done until those who are to do them are prepared to do them. Any change in the routine of an institution has to be evaluated by its participants, and will not be integrated into this routine until these participants find no dichotomy between the change and the actions which have so far been enough to ensure their continued participation.

When an institution like the architectural profession is confronted with more change in its environment than its participants have been used to, they are forced to a re-evaluation of the meaning or function of the institution. They must either conform to a new set of determinants, or accept the fact that their meaning or function is of less importance to society.

Architects, of course, rejected the second option, and have coped with the impact of technology on their professional role by slowly redefining the function of the profession. As building scale increased, and new materials became available, members of the profession relinquished responsibility for <u>firmitas</u>. As the 'fine tuning' of the internal environment became easier and easier through a command of technology, which was part of the set of 'correct actions' of other professional roles, they relinquished this responsibility too.

They extended their responsibility to include the sort of buildings which had previously been the work of anonymous builders, and in this way placed a new importance on the sculptural and 'formal' contributions to the art of the culture which these buildings made.

To a large extent this is the raison d'etre of the profession. But the importance of the 'grand statement' is diminishing in a society beginning to see value in the preservation of what is, rather than in a rejection of older values, a rejection natural in a period when an apparently unlimited supply of energy promised a better model world each year, and devalued the world that was. The experience of limited growth over the last few years has meant that the meaning/function of many institutions has not atrophied at the pace of the 1950's and 1960's.

Many architects, however, continue to defend the profession from this atrophy, and do so in terms of its artictic and stylistic contributions. Art and style are, however, to a large extent overt expressions of a synthesis of the functions of an artifact. To defend a profession which has given up its function as it relinquished the responsibilities outlined above, on the basis of its stylistic contribution alone, is like trying to defend an institution like aristocracy on the basis of its undoubted contribution to the world's vestigial elegance.

Style and elegance <u>are</u> important, but to have any value they must be expressions of a relationship between stylish and elegant people and the world beyond them. The inconsequentiality of the relationship of those who are only 'stylish' with the rest of us does not quite exemplify the relationship of the profession to the rest of the world, but there is some similarity there.

Architectural elegance, style, charm, wit, <u>&c</u>. is not the only reason for the importance of the profession. It is, certainly, an important contribution, but it is even more contributory when, in contrast to the <u>contrived</u> expression of structure or function in the case of the 'rationalist', it is a <u>spontaneous</u> (almost involuntary) expression of the synthesis of the numerous functions of the building. The hard technological involvement called for from the architect in the case of 'passive' design is not inimical to the artistic expression which is important to him. Indeed, it makes this expression even more valuable.

The problem of introducing this technological involvement into the set of 'correct actions' which define the role of the architect is not insurmountable. It has been overcome, to some extent, already. The acceleration of the acceptance of these actions into the routine of the profession is not a major institutional problem, for existing programs will have to suffer only minor modifications before serving the purpose of making real energy conscious design the responsibility of the architectural profession again.

REFERENCES

1. ETZIONI, A., A Comparitive Analysis of Complex Organizations, New York: Free Press, 1971, p. xi.

2. DEUTSCH, C., The Nerves of Government, New York: Free Press, 1966, p. 77.

3. ibid., p. 129.

4. ibid., p. 146.

5. LAWRENCE, P. & LORSCH, J., Developing Organizations, Reading, Mass.: Addison-Wesley Publishing Co., 1969, p. 2.

6. ibid., p. 3.

7. "Bids Rigged; Two companies cop a plea", TIME, December 25, 1978, p. 59.

8. HAWORTH, L., "Do Organizations Act?", ETHICS, vol. 70, 1959, pp. 59-63.

9. ibid., p. 60.

10. ibid., p. 60.

11. ibid., p. 61.

12. ibid., p. 63.

13. ibid., p. 63.

14. ibid., p. 60.

15. DARWIN, C., The Origin Of Species, New York: Mentor Books, 1958, p. 139.

16. MARCH, J. & SIMON, H., <u>Organizations</u>, New York: John Wiley & Sons, 1958.

17. ETZIONI, A., <u>op</u>. <u>cit</u>., p. 21.

18. <u>ibid</u>., p. xi.

19. <u>ibid</u>., p. 3.

20. <u>ibid</u>., p. 3.

21. <u>ibid</u>., p. 4.

22. <u>ibid</u>., pp. 9-10.

23. <u>ibid</u>., p. 12.

24. <u>ibid</u>., p. 14.

25. NUTT-POWELL, T., <u>et</u> <u>al</u>., Toward a Theory of Institutional Analysis, Energy Laboratory Report (MIT-EL-78-020), p.5.

26. <u>ibid</u>., pp. 3-4.

27. <u>ibid</u>., p. 20.

28. <u>ibid</u>., p. 21.

29. Shorter Oxford English Dictionary.

30. DEUTSCH, C., <u>op</u>. <u>cit</u>., p. 37.

31. WEBER, M., <u>The Theory of Social & Economic Organization</u>, New York: Free Press, 1964, p. 93.

32. HAVELOCK, R.G., <u>Planning for Innovation</u>, Ann Arbor: The University of Michigan, 1971, p. 10-30.

33. <u>ibid</u>., p. 10-33.

34. <u>ibid</u>., p. 10-31.

35. "Ruth Hill became an Indian to write epic of the Sioux", SMITHSONIAN, December, 1978, p. 122.

36. NUTT- POWELL, T., *et al*., *op*. *cit*., p. 33.

37. LE CORBUSIER, *Towards a New Architecture*., London: The Architectural Press, 1970, p. 100.

38. BACON, E., *The Design of Cities*, New York: Viking, 1974, p. 49.

39. VENTURI, R., *Complexity and Contradiction in Modern Architecture*, New York: Doubleday, 1966, p. 17.

40. RAPAPORT, A., *House Form and Culture*, Englewood Cliffs, N.J.: Prentice Hall,

41. FURLONG, M., & NUTT-POWELL, T., *Institutional Analysis of Research and Socialization in Housing: A Preliminary Exploration*, MIT Energy Laboratory Working Paper (MIT-EL-79-015WP), March, 1979, p. 20.

ADDITIONAL
BIBLIOGRAPHY

BANHAM, R., The Architecture of the Well Tempered Environment, London, The Architectural Press, 1973.

CLARK, W., Energy for Survival, Garden City, N.Y.: Anchor Press, 1975.

COLLINS, P., Changing Ideals in Modern Architecture 1750-1950, London: Faber & Faber, 1965.

CULLEN, G., Townscape, London: The Architectural Press, 1968.

DUFFIE, J.A. & BECKMAN, W.A., Solar Energy Thermal Processes, New York: John Wiley & Sons, 1974.

GIEDION, S., Space, Time, & Architecture, Cambridge: Harvard University Press, 1963.

GIVONI, B., Man, Climate, & Architecture, London: Applied Science Publishers, 1976

GRIFFIN, C.W., Energy Conservation in Buildings, Washington: The Construction Specification Institute, 1974.

HABRAKEN, N.J., Supports, New York: Praeger, 1972.

JENCKS, C., Architecture 2000, New York: Praeger, 1973.

Le Corbusier & the Tragic View of Architecture, Cambridge: Harvard University Press, 1973.

Modern Movements in Architecture, Hammondsworth, England, Penguin, 1973.

KOPAY, D, & YOUNG,P.D., The David Kopay Story,New York: Bantam, 1977.

LE CORBUSIER, Towards a New Architecture, London: The Architecture Press, 1970.

MC.HARG, I., Design With Nature, Garden City, N.Y.: Doubleday, 1969.

MUMFORD, L., The City in History, New York: Harcourt, Brace & World, 1961.

Roots of Contemporary American Culture, New York: Dover, 1972.

Technics & Human Development, New York: Harvest, 1966.

OLGYAY, V., Design with Climate, Princeton: Princeton University Press, 1966.

PEVSNER, N., An Outline of European Architecture, Hammondsworth, England: Penguin, 1968.

ROETHLISBERGER, F.J. & DICKSON, W.J., Management and the Worker.Cambridge: Harvard University Press, 1975.

RUDOFSKY, B., Architecture Without Architects, Garden City, N.Y.: Doubleday, 1964.

SILVERMAN, D., The Theory of Organizations, New York: Basic Books, 1971.

STEADMAN, P., Energy, Environment, & Building, London: Cambridge University Press, 1975.

TOYNBEE, A.J., A Study of History, New York: Dell, 1965.

WILLS, G., Confessions of a Conservative, New York: Doubleday, 1979.

WRIGHT, F.L., The Natural House, New York: Horizon, 1954.

ZALTMAN, G., DUNCAN, R., & HOLBEK, J., Innovations & Organizations, New York: John Wiley & Sons, 1973.

APPENDIX 1 MODIFIED 'PASSIVE' DESIGN METHOD

MODIFIED DIRECT GAIN PASSIVE DESIGN METHOD.
(FOR MULTIPLE ORIENTATIONS)

1. A. Use 'Solar angles and Radiation' program to determine, at various angles of orientation:
   - i clear day beam radiation, transmitted (CBT) and incident (CBI)
   - ii clear day diffuse radiation, transmitted (CDT) and incident (CDI)

   B. Calculate transmission factors:
   - i beam transmission factor (BTF) = CBT/CBI
   - ii diffuse transmission factor (DTF) = CDT/CDI

2. Use 'Average Daily Radiation' program to determine:
   - i average beam radiation BR(Av)
   - ii average diffuse radiation DR(Av)
   - iii average reflected radiation RR(Av)

3. Calculate correct reflected radiation;
   - i at orientation where beam radiation is highest, find ratio of BR(Av) to DR(Av), such that BR(Av) + DR(Av) = 1.000
   - ii at same orientation separate RR(Av) into beam component [RR(Av)B] and diffuse component [RR(Av)D], using 3.i ratios such that [RR(Av)B] and [RR(Av)D] = RR(Av)
   - iii find factors, BRF, relating BR(Av) at any orientation to BR(Av) at orientation where BR(Av) is highest
   - iv find correct reflected radiation, RR(C) at each orientation by:
     - a. multiplying [RR(Av)B] by BRF
     - b. add to RR(Av)D

4. Find total average transmitted radiation

from:

i BR(Av) x BTF = actual beam radiation (BRA)

ii DR(Av) x DTF = actual diffuse radiation (DRA)

iii RR(C) x DTF = actual reflected radiation (RRA)

iv BRA + DRA + RRA = average transmitted radiation per sq. ft. at any particular orientation

v multiply each total by glass area

vi sum the radiation transmitted at each orientation to get monthly average day transmitted radiation for entire building (MR)

vii MR x days in month = monthly gain (MG)

5. Use 'Bin Data' program to find monthly heating load (ML)

6. Use 'Niles" program to calculate overheating during critical months (i.e. at turn of heating season)

7. A. Calculate Net and Gross Monthly Heating Fractions:

i Net fraction = MG/ML

ii Gross fraction = MG/(ML + Internal Gains)

B. Calculate Net and Gross Seasonal Heating Fractions:

i Net fraction = Sum of MG(Nov.-May)/ML(Nov.-May)

ii Gross fraction = Sum of MG(Nov.-May)/ [MR+Int Gain](Nov.-May)

APPENDIX 2 CALCULATIONS

1. WINDOW, WALL, AND SLAB AREA

WINDOWS:

ORIENTATION	TOTAL AREA	GLASS AREA
0^{o}	611	550
-35	366	330
-90	115	105
-105	313	280
-135	313	280
-165	1008	910
ROOF*	1004	905

WALLS:	180
SLAB:	1527
SOLID ROOF:	180

2. 'U' VALUES

WINDOWS:	.275
WALLS:	.067
SLAB$^{\phi}$:	.090
SOLID ROOF:	.050

*ROOF ORIENTATION: SLOPE 15^{o}
AZIMUTH -35^{o}

$^{\phi}$SLAB: 8" CONCRETE,2" FIBERGLASS

3. 'UxA' VALUES

WINDOWS:	1097.7
WALLS:	12.1
ROOF:	5.4
SLAB:	137.4

4. VOLUME

30,312 FT.

5. INFILTRATION

.5 AIR CHANGES/HR.	272.81	BTU/HR.
5.0 AIR CHANGES/HR.	2728.10	
AVERAGE	1091.2	

6. INTERNAL GAINS (FROM RESTAURANT OPERATION -- 8 HRS)

PEOPLE:	8000	
LIGHTS:	614	
TOTAL:	8614	BTU/HR.

7. SLAB LOSS

3435 BTU/HR.

8. EFFECTIVE "INTERNAL GAINS"

INTERNAL GAINS:	8614	
LESS SLAB LOSS:	3435	
	5180	BTU/HR.

9. EFFECTIVE "UxA"

UxA - WINDOWS:	1097.7	
WALLS:	12.1	
ROOF:	5.4	
	1115.2	
PLUS INFILTRATION:		
0.5 AIR CHANGES	1115.2	
	272.8	
	1388.0	BTU/HR.
5.0 AIR CHANGES	1115.2	
	2728.1	
	3843.2	BTU/HR
AVERAGE	1115.2	
	1091.2	
	2206.4	BTU/HR.

10. EFFECTIVE "UxA" EXPRESSED AS ^{o}F

"INTERNAL GAINS"/"UxA"

0.5 AIR CHANGES	6.2^{o}
5.0 AIR CHANGES	2.2
AVERAGE	3.9

11. KITCHEN CONTRIBUTION

APPLIANCES:

OVEN/RANGE	60,000
DISH WASHER	27,312
FREEZER/FRIDGE	5,121
COFFEE MAKER	12,362
BROILER	60,000
FOOD WARMER	3,414
	168,480 BTU/HR
	1,347,840 BTU/8 HR. DAY

	BTU/MONTH
OCTOBER	27,158,975
NOVEMBER	26,282,880
DECEMBER	27,158.975
JANUARY	27,158,975
FEBRUARY	24,530,688
MARCH	27,158,975
APRIL	26,282,880
MAY	27,158,975

12. MONTHLY SOLAR GAIN

SEE FOLLOWING PAGES

JANUARY

A. TRANSMITTED CLEAR DAY RADIATION:

ORIENTATION	INSOLATION					
	BEAM			DIFFUSE		
	TRANS	INC	FACTOR	TRANS	INC	FACTOR
0	897.4	1373.5	.653	139.9	230.1	.608
-35	700.8	1125.4	.623	"	"	"
-90	226.8	373.8	.607	"	"	"
-105	120.5	211.1	.571	"	"	"
-135	2.6	15.9	.164	"	"	"
-165	-	-	-	"	"	"
ROOF	58.0	521.9	.111	15.1	102.6	.147

B. CALCULATING REFLECTED RADIATION:

	INSOLATION	RATIO
HIGHEST AVERAGE DAY BEAM:	695.5	.856
AVERAGE DAY DIFFUSE:	116.9	.144
	812.4	1.000

REFLECTED (AT HIGHEST BEAM ORIENTATION)

BEAM COMPONENT:	108.2
DIFFUSE COMPONENT:	18.2
TOTAL REFLECTED:	126.4

ORIENTATION	BEAM/ HIGHEST BEAM	BEAM	REFLECTED DIFFUSE	TOTAL
0	1.000	108.2	18.2	126.4
-35	.826	89.4	18.2	107.6
-90	.335	36.2	18.2	54.4
-105	.146	15.8	18.2	34.0
-135	-	-	18.2	18.2
-165	-	-	18.2	18.2

E. <u>JANUARY MONTHLY LOAD</u>:

BALANCE POINT:	54.4
DEGREE HOURS:	21,710.4
DEGREE DAYS:	904.6
BTU'S NEEDED IN JANUARY:	47,901,815

F. <u>NET JANUARY SOLAR FRACTION</u>:

22,137,875/47,901,815 = 46.2%

G. <u>GROSS JANUARY SOLAR FRACTION</u>:

22,137,875/(47,901,815 + 6,408,816*) = 41.8%

* MONTHLY INTERNAL GAINS

C. AVERAGE DAILY RADIATION TRANSMITTED:

ORIENT.		INCID. RAD.	TRANS. FACTOR	TRANS. RAD.	GLASS AREA	TOT. RAD. TRANS.
0	BEAM	695.5	.653	454.2		
	DIFF	116.9	.608	71.1		
	REFL	126.4	.608	76.9		
	TOT			602.2	550	331,210
-35	BEAM	574.5	.623	357.9		
	DIFF	116.9	.608	71.1		
	REFL	107.6	.608	65.4		
	TOT			494.4	330	163,152
-90	BEAM	233.1	.607	141.5		
	DIFF	116.9	.608	71.1		
	REFL	54.4	.608	33.1		
	TOT			245.7	105	25,798
-105	BEAM	101.6	.571	58.0		
	DIFF	116.9	.608	71.1		
	REFL	34.0	.608	21.0		
	TOT			150.1	280	42,028
-135	BEAM	-	-	-		
	DIFF	116.9	.608	71.1		
	REFL	18.2	.608	11.1		
	TOT			82.2	280	23,016
-165	BEAM	-	-	-		
	DIFF	116.9	.608	71.1		
	REFL	18.2	.608	11.1		
	TOT			82.2	910	74,802
ROOF	BEAM	229.2	.111	25.4		
	DIFF	233.1	.147	34.3		
	REFL	.8	.147	.1		
	TOT			59.8	905	54,119
						714,125

D. MONTHLY AVERAGE TRANSMITTED RADIATION:

714,125 x 31 = 22,137,875 BTU/JANUARY

FEBRUARY

A. TRANSMITTED CLEAR DAY RADIATION:

ORIENTATION	INSOLATION					
	BEAM			DIFFUSE		
	TRANS	INC	FACTOR	TRANS	INC	FACTOR
0	913.9	1412.4	.647	147.6	242.8	.608
-35	743.3	1181.8	.629	"	"	"
-90	323.0	521.4	.619	"	"	"
-105	202.7	347.3	.584	"	"	"
-135	32.5	74.9	.434	"	"	"
-165	-	-	-	"	"	"
ROOF	114.6	859.7	.133	18.9	128.5	.147

B. CALCULATING REFLECTED RADIATION:

	INSOLATION	RATIO
HIGHEST AVERAGE DAY BEAM:	723.4	.818
AVERAGE DAY DIFFUSE:	161.0	.182
	884.4	1.000

REFLECTED (AT HIGHEST BEAM ORIENTATION)

BEAM COMPONENT:	99.6
DIFFUSE COMPONENT:	22.2
TOTAL REFLECTED:	121.8

ORIENTATION	BEAM / HIGHEST BEAM	BEAM	REFLECTED DIFFUSE	TOTAL
0	1.000	99.6	22.2	121.8
-35	.700	85.3	22.2	107.5
-90	.363	44.2	22.2	66.4
-105	.212	25.8	22.2	48.0
-135	-	-	22.2	22.2
-165	-	-	22.2	22.2

C. AVERAGE DAILY RADIATION TRANSMITTED

ORIENT		INCID. RAD.	TRANS. FACTOR	TRANS. RAD.	GLASS AREA	TOT. RAD. TRANS.
0	BEAM	723.4	.647	468.0		
	DIFF	161.0	.608	97.9		
	REFL	121.8	.608	74.1		
	TOT			640.0	550	352,000
-35	BEAM	619.3	.629	389.5		
	DIFF	161.0	.608	97.9		
	REFL	107.5	.608	65.4		
	TOT			552.8	330	182,424
-90	BEAM	321.2	.619	198.8		
	DIFF	161.0	.608	97.9		
	REFL	66.4	.608	40.4		
	TOT			337.1	105	35,396
-105	BEAM	187.2	.584	109.3		
	DIFF	161.0	.608	97.9		
	REFL	48.0	.608	29.2		
	TOT			236.4	280	66,192
-135	BEAM	-	-	-		
	DIFF	161.0	.608	97.9		
	REFL	22.2	.608	13.5		
	TOT			114.4	280	31,192
-165	BEAM	-	-	-		
	DIFF	161.0	.608	97.9		
	REFL	22.2	.608	13.5		
	TOT			114.4	910	104,104
ROOF	BEAM	369.9	.133	49.2		
	DIFF	321.0	.147	47.2		
	REFL	0.8	.146	.1		
	TOT			96.5	950	87,332
						858,640

D. MONTHLY AVERAGE TRANSMITTED RADIATION:

858,640 x 28 = 24,041,920 BTU/FEBRUARY

E. <u>FEBRUARY MONTHLY LOAD</u>:

BALANCE POINT:	54.4
DEGREE HOURS:	18,805.4
DEGREE DAYS:	783.6
BTU'S NEEDED IN FEBRUARY:	41,492,322

F. <u>NET FEBRUARY SOLAR FRACTION</u>:

24,041,920/41,492,322 = 57.9%

G. <u>GROSS FEBRUARY SOLAR FRACTION</u>:

24,041,920/(41,492,322 + 5,788,608) = 50.8%

MARCH

A. TRANSMITTED CLEAR DAY RADIATION:

ORIENTATION	INSOLATION					
	BEAM			DIFFUSE		
	TRANS	INC	FACTOR	TRANS	INC	FACTOR
0	731.5	1216.9	.601	144.5	237.6	.608
-35	673.3	1110.3	.606	"	"	"
-90	428.1	690.1	.620	"	"	"
-105	315.8	528.5	.598	"	"	"
-135	94.4	199.6	.473	"	"	"
-165	2.2	13.3	.165	"	"	"
ROOF	183.0	1248.1	.147	25.6	174.1	.147

B. CALCULATING REFLECTED RADIATION:

	INSOLATION	RATIO
HIGHEST AVERAGE DAY BEAM:	645.2	.743
AVERAGE DAY DIFFUSE:	222.8	.257
	868.0	1.000

REFLECTED (AT HIGHEST BEAM ORIENTATION)
BEAM COMPONENT: 79.3
DIFFUSE COMPONENT: 27.4
TOTAL REFLECTED: 106.7

ORIENTATION	BEAM/ HIGHEST BEAM	BEAM	REFLECTED DIFFUSE	TOTAL
0	1.000	79.3	27.4	106.7
-35	.960	76.1	27.4	103.5
-90	.667	52.9	27.4	80.3
-105	.479	38.0	27.4	65.4
-135	-	-	27.4	27.4
-165	-	-	27.4	27.4

C. AVERAGE DAILY RADIATION TRANSMITTED:

ORIENT.		INCID. RAD	TRANS. FACTOR	TRANS. RAD.	GLASS AREA	TOT. RAD. TRANS.
0	BEAM	645.2	.601	387.8		
	DIFF	228.8	.608	139.1		
	REFL	106.7	.608	64.9		
	TOT			591.8	550	325,490
-35	BEAM	619.4	.606	408.8		
	DIFF	228.8	.608	139.1		
	REFL	103.5	.608	62.9		
	TOT			610.8	330	201,564
-90	BEAM	430.1	.620	266.7		
	DIFF	228.8	.608	139.1		
	REFL	80.3	.608	48.8		
	TOT			454.6	105	47,733
-105	BEAM	309.2	.598	184.9		
	DIFF	228.8	.608	139.1		
	REFL	65.4	.608	39.8		
	TOT			363.8	280	101,864
-135	BEAM	-	.473	-		
	DIFF	228.8	.608	139.1		
	REFL	27.4	.608	16.7		
	TOT			155.8	280	43,624
-165	BEAM	-	.165	-		
	DIFF	228.8	.608	139.1		
	REFL	27.4	.608	16.7		
	TOT			155.8	910	141,778
ROOF	BEAM	578.5	.147	85.1		
	DIFF	444.3	.147	65.3		
	REFL	.7	.147	.1		
	TOT			150.5	905	136,202
						998,255

D. MONTHLY AVERAGE TRANSMITTED RADIATION:

998,255 x 31 = 30,945,905 BTU/MARCH

E. <u>MARCH MONTHLY LOAD</u>:

BALANCE POINT:	54.4
DEGREE HOURS:	14,802.8
DEGREE DAYS:	616.8
BTU'S NEEDED IN MARCH:	32,660,806

F. <u>NET MARCH SOLAR FRACTION</u>:

30,945,905/32,660,806 = 94.7%

G. <u>GROSS MARCH SOLAR FRACTION</u>:

30,945,905/(32,660,806 + 6,408,816) = 79.2%

APRIL

A. TRANSMITTED CLEAR DAY RADIATION:

ORIENTATION	INSOLATION					
	BEAM			DIFFUSE		
	TRANS	INC	FACTOR	TRANS	INC	FACTOR
0	421.3	807.5	.522	192.1	316.0	.608
-35	536.1	887.4	.604	"	"	"
-90	472.8	764.3	.619	"	"	"
-105	395.5	645.4	.613	"	"	"
-135	197.2	346.8	.569	"	"	"
-165	33.7	78.0	.432	"	"	"
ROOF	242.9	1577.0	.154	37.3	253.7	.147

B. CALCULATING REFLECTED RADIATION:

	INSOLATION	RATIO
HIGHEST AVERAGE DAY BEAM:	500.9	.635
AVERAGE DAY DIFFUSE:	287.6	.365
	788.5	1.000

REFLECTED (AT HIGHEST BEAM ORIENTATION)

BEAM COMPONENT:	86.1
DIFFUSE COMPONENT:	49.4
TOTAL REFLECTED:	135.5

ORIENTATION	BEAM/ HIGHEST BEAM	BEAM	REFLECTED DIFFUSE	TOTAL
0	.832	71.6	49.4	121.0
-35	1.000	86.1	49.4	135.5
-90	.971	83.4	49.4	133.0
-105	.813	70.0	49.4	119.4
-135	.191	16.4	49.4	65.8
-165	-	-	49.4	49.4

C. <u>AVERAGE DAILY RADIATION TRANSMITTED</u>:

ORIENT.		INCID. RAD.	TRANS. FACTOR	TRANS. RAD.	GLASS AREA	TOT. RAD. TRANS.
0	BEAM	416.5	.522	217.4		
	DIFF	287.6	.608	174.9		
	REFL	121.0	.608	73.6		
	TOT			465.9	550	256,245
-35	BEAM	500.9	.604	302.5		
	DIFF	287.6	.608	174.9		
	REFL	135.5	.608	82.4		
	TOT			559.8	330	184,734
-90	BEAM	486.5	.619	301.1		
	DIFF	287.6	.608	174.9		
	REFL	133.0	.608	80.9		
	TOT			556.9	105	58,474
-105	BEAM	407.0	.613	249.5		
	DIFF	287.6	.608	174.9		
	REFL	119.4	.608	72.6		
	TOT			497.0	280	139,160
-135	BEAM	95.6	.569	54.4		
	DIFF	287.6	.608	174.9		
	REFL	65.8	.608	40.0		
	TOT			269.3	280	75,404
-165	BEAM	-	.432	-		
	DIFF	287.6	.608	174.9		
	REFL	49.4	.608	30.0		
	TOT			204.9	910	186,459
ROOF	BEAM	751.8	.154	115.8		
	DIFF	573.3	.147	84.3		
	REFL	.9	.147	.1		
	TOT			200.2	905	181,181
						1,081,657

D. <u>MONTHLY AVERAGE TRANSMITTED RADIATION</u>:

1,081,657 x 30 = 32,449,710 BTU/APRIL

E. APRIL MONTHLY LOAD:

BALANCE POINT:	54.4
DEGREE HOURS:	7,249.0
DEGREE DAYS:	302.0
BTU'S NEEDED IN APRIL:	15,994,259

F. NET APRIL SOLAR FRACTION:

32,449,710/15,994,259 = 202.9%

G. GROSS APRIL SOLAR FRACTION:

32,449,710/(15,994,259 + 6,202,080)= 144.8%

MAY

A. TRANSMITTED CLEAR DAY RADIATION:

ORIENTATION	INSOLATION					
	BEAM			DIFFUSE		
	TRANS	INC	FACTOR	TRANS	INC	FACTOR
0	212.9	514.9	.413	231.5	380.7	.608
-35	375.9	697.8	.539	"	"	"
-90	496.8	801.5	.620	"	"	"
-105	442.4	722.3	.612	"	"	"
-135	268.4	466.2	.576	"	"	"
-165	71.2	170.6	.417	"	"	"
ROOF	275.5	1790.4	.154	48.5	330.0	.147

B. CALCULATING REFLECTED RADIATION:

	INSOLATION	RATIO
HIGHEST AVERAGE DAY BEAM:	643.8	.663
AVERAGE DAY DIFFUSE:	326.9	.337
	970.7	1.000

REFLECTED (AT HIGHEST BEAM ORIENTATION)

BEAM COMPONENT:	117.3
DIFFUSE COMPONENT:	59.6
TOTAL REFLECTED:	176.9

ORIENTATION	BEAM/ HIGHEST BEAM	REFLECTED BEAM	REFLECTED DIFFUSE	TOTAL
0	.498	58.5	59.6	118.1
-35	.748	87.7	59.6	147.3
-90	1.000	117.3	59.6	176.9
-105	.919	107.8	59.6	167.4
-135	.494	58.0	59.6	117.6
-165	-	-	59.6	59.6

C. AVERAGE DAILY RADIATION TRANSMITTED:

ORIENT.		INCID. RAD.	TRANS. FACTOR	TRANS. RAD.	GLASS AREA	TOT. RAD. TRANS.
0	BEAM	320.9	.413	132.5		
	DIFF	326.9	.608	198.8		
	REFL	118.1	.608	71.8		
	TOT			403.1	550	221,705
-35	BEAM	481.3	.539	259.4		
	DIFF	326.9	.608	198.8		
	REFL	147.3	.608	89.6		
	TOT			547.8	330	180,774
-90	BEAM	643.8	.620	399.2		
	DIFF	326.9	.608	198.8		
	REFL	176.9	.608	107.6		
	TOT			705.6	105	74,088
-105	BEAM	591.7	.612	362.1		
	DIFF	326.9	.608	198.8		
	REFL	167.4	.608	101.8		
	TOT			662.7	280	185,556
-135	BEAM	318.2	.576	183.3		
	DIFF	326.9	.608	198.8		
	REFL	117.6	.608	71.5		
	TOT			453.6	280	127,008
-165	BEAM	-	.417	-		
	DIFF	326.9	.608	198.8		
	REFL	59.6	.608	36.2		
	TOT			235.0	910	213,850
ROOF	BEAM	1098.7	.154	169.2		
	DIFF	651.7	.147	95.8		
	REFL	1.1	.147	.2		
	TOT			265.2	905	240,006
						1,242,987

D. MONTHLY AVERAGE TRANSMITTED RADIATION:

1,242,987 x 31 = 38,532,597 BTU'S/MAY

E. MAY MONTHLY LOAD:

BALANCE POINT:	54.4
DEGREE HOURS:	2,338.0
DEGREE DAYS:	97.4
BTU'S NEEDED IN MAY:	5,158,621

F. NET MAY SOLAR FRACTION:

38,532,597/5,158,621 = 747.0%

G. GROSS MAY SOLAR FRACTION:

38,532,597/(5,158,621 + 6,408,816) = 331.9%

JUNE

A. TRANSMITTED CLEAR DAY RADIATION:

ORIENTATION	INSOLATION					
	BEAM			DIFFUSE		
	TRANS	INC	FACTOR	TRANS	INC	FACTOR
0	155.4	402.7	.386	248.3	408.4	.608
-35	311.3	606.9	.513	"	"	"
-90	493.7	789.8	.625	"	"	"
-105	451.1	732.2	.616	"	"	"
-135	290.0	500.8	.579	"	"	"
-165	89.0	214.6	.415	"	"	"
ROOF	283.9	1853.8	.153	54.0	367.1	.147

B. CALCULATING REFLECTED RADIATION:

	INSOLATION	RATIO
HIGHEST AVERAGE DAY BEAM:	651.1	.652
AVERAGE DAY DIFFUSE:	347.6	.348
	998.7	1.000

REFLECTED (AT HIGHEST BEAM ORIENTATION)

BEAM COMPONENT:	121.5
DIFFUSE COMPONENT:	64.9
TOTAL REFLECTED:	186.4

ORIENTATION	BEAM/ HIGHEST BEAM	REFLECTED BEAM	REFLECTED DIFFUSE	TOTAL
0	.366	44.5	64.9	109.4
-35	.622	75.6	64.9	140.5
-90	1.000	121.5	64.9	186.4
-105	.956	116.2	64.9	181.1
-135	.622	75.5	64.9	140.4
-165	-	-	64.9	64.9

C. <u>AVERAGE DAILY RADIATION TRANSMITTED</u>:

ORIENT.		INCID. RAD.	TRANS. FACTOR	TRANS. RAD.	GLASS AREA	TOT. RAD. TRANS.
0	BEAM	238.3	.386	92.0		
	DIFF	347.6	.608	211.3		
	REFL	109.4	.608	66.5		
	TOT			369.8	550	203,390
-35	BEAM	405.0	.513	207.8		
	DIFF	347.6	.608	211.3		
	REFL	140.5	.608	85.4		
	TOT			504.5	330	166,485
-90	BEAM	651.1	.625	406.9		
	DIFF	347.6	.608	211.3		
	REFL	186.4	.608	113.3		
	TOT			731.5	105	76,807
-105	BEAM	622.6	.616	383.5		
	DIFF	347.6	.608	211.3		
	REFL	181.1	.608	110.1		
	TOT			704.9	280	197,372
-135	BEAM	404.7	.579	249.3		
	DIFF	347.6	.608	211.3		
	REFL	140.4	.608	85.4		
	TOT			546.0	280	152,880
-165	BEAM	-	.415	-		
	DIFF	347.6	.608	211.3		
	REFL	64.9	.608	39.5		
	TOT			250.8	910	228,228
ROOF	BEAM	1162.2	.153	177.8		
	DIFF	692.9	.147	101.9		
	REFL	1.2	.147	.2		
	TOT			279.9	905	253,310
						1,280,672

JULY

A. TRANSMITED CLEAR DAY RADIATION:

ORIENTATION	INSOLATION					
	BEAM			DIFFUSE		
	TRANS	INC	FACTOR	TRANS	INC	FACTOR
0	201.3	489.3	.416	239.0	393.1	.608
-35	368.6	658.0	.560	"	"	"
-90	479.4	763.8	.628	"	"	"
-105	418.3	694.7	.602	"	"	"
-135	257.9	450.3	.573	"	"	"
-165	71.0	161.8	.439	"	"	"
ROOF	270.0	1759.6	.154	52.6	357.8	.147

B. CALCULATING REFLECTED RADIATION:

	INSOLATION	RATIO
HIGHEST AVERAGE DAY BEAM:	670.8	.665
AVERAGE DAY DIFFUSE:	337.6	.335
	1008.4	1.000

REFLECTED (AT HIGHEST BEAM ORIENTATION)

BEAM COMPONENT:	123.8
DIFFUSE COMPONENT:	62.3
TOTAL REFLECTED:	186.1

ORIENTATION	BEAM/ HIGHEST BEAM	REFLECTED BEAM	REFLECTED DIFFUSE	TOTAL
0	.423	52.3	62.3	114.6
-35	.698	86.4	62.3	148.7
-90	1.000	123.8	62.3	186.1
-105	.968	119.9	62.3	182.2
-135	.583	72.1	62.3	134.4
-165	-	-	62.3	62.3

C. <u>AVERAGE DAILY RADIATION TRANSMITTED</u>:

ORIENT.		INCID. RAD.	TRANS. FACTOR	TRANS. RAD.	GLASS AREA	TOT. RAD. TRANS.
0	BEAM	283.5	.417	118.2		
	DIFF	337.6	.607	205.3		
	REFL	114.6	.608	69.7		
	TOT			393.2	550	216,260
-35	BEAM	454.6	.560	254.6		
	DIFF	337.6	.608	205.3		
	REFL	148.7	.608	90.4		
	TOT			550.3	330	181,599
-90	BEAM	670.8	.628	421.3		
	DIFF	337.6	.608	205.2		
	REFL	186.1	.608	113.1		
	TOT			739.7	105	77,688
-105	BEAM	630.4	.602	397.5		
	DIFF	337.6	.608	205.3		
	REFL	182.2	.608	110.8		
	TOT			695.6	280	194,768
-135	BEAM	379.3	.573	217.3		
	DIFF	337.6	.608	205.3		
	REFL	134.4	.608	81.7		
	TOT			504.3	280	141,204
-165	BEAM	-	.439	-		
	DIFF	337.6	.608	205.3		
	REFL	62.3	.608	37.9		
	TOT			243.2	910	221,312
ROOF	BEAM	1173.7	.154	180.7		
	DIFF	673.1	.147	98.9		
	REFL	1.2	.147	.2		
	TOT			279.8	905	253,219
						1,286,030

AUGUST

A. TRANSMITTED CLEAR DAY RADIATION:

ORIENTATION	INSOLATION					
	BEAM			DIFFUSE		
	TRANS	INC	FACTOR	TRANS	INC	FACTOR
0	390.4	744.4	.524	205.2	337.5	.608
-35	498.8	824.0	.605	"	"	"
-90	444.3	717.2	.619	"	"	"
-105	361.1	608.0	.594	"	"	"
-135	187.3	329.6	.568	"	"	"
-165	33.0	76.1	.434	"	"	"
ROOF	232.9	1512.8	.154	44.3	301.1	.147

B. CALCULATING REFLECTED RADIATION:

	INSOLATION	RATIO
HIGHEST AVERAGE DAY BEAM:	581.8	.658
AVARAGE DAY DIFFUSE:	302.8	.342
	884.6	1.000

REFLECTED (AT HIGHEST BEAM COMPONENT)

BEAM COMPONENT:	103.8
DIFFUSE COMPONENT:	54.0
TOTAL REFLECTED:	157.8

ORIENTATION	BEAM/ HIGHEST BEAM	REFLECTED BEAM	REFLECTED DIFFUSE	TOTAL
0	.689	71.5	54.0	125.5
-35	.905	93.9	54.0	148.0
-90	1.000	103.8	54.0	157.8
-105	.873	90.6	54.0	144.6
-135	.329	34.2	54.0	88.2
-165	-	-	54.0	54.0

C. <u>AVERAGE DAILY RADIATION TRANSMITTED</u>:

ORIENT.	INCID. RAD.	TRANS. FACTOR	TRANS. RAD.	GLASS AREA	TOT. RAD. TRANS.
0	400.9	.524	210.1		
	302.8	.608	184.1		
	125.5	.608	76.3		
			470.5	550	258,775
-35	526.8	.605	318.7		
	302.8	.608	184.1		
	148.0	.608	90.0		
			408.7	330	134,871
-90	581.8	.619	360.1		
	302.8	.608	184.1		
	157.8	.608	95.9		
			640.1	105	67,210
-105	507.7	.594	301.6		
	302.8	.608	184.1		
	144.6	.608	87.9		
			573.6	280	160,608
-135	191.6	.568	108.8		
	302.8	.608	184.1		
	88.2	.608	53.6		
			346.5	280	97,020
-165	-	.434	-		
	302.8	.608	184.1		
	54.0	.608	32.8		
			216.9	910	197,397
ROOF	938.8	.154	144.6		
	603.8	.147	88.8		
	1.0	.147	.1		
			233.5	905	211,317
					1,127,198

SEPTEMBER

A. TRANSMITTED CLEAR DAY RADIATION:

ORIENTATION	INSOLATION					
	BEAM			DIFFUSE		
	TRANS	INC	FACTOR	TRANS	INC	FACTOR
0	682.6	1135.1	.601	151.9	249.9	.608
-35	654.0	1034.4	.632	"	"	"
-90	389.6	635.6	.613	"	"	"
-105	288.7	480.5	.601	"	"	"
-135	84.8	179.6	.472	"	"	"
-165	1.7	10.4	.163	"	"	"
ROOF	173.3	1164.4	.149	30.8	209.3	.147

B. CALCULATING REFLECTED RADIATION:

	INSOLATION	RATIO
HIGHEST AVERAGE DAY BEAM:	652.1	.726
AVERAGE DAY DIFFUSE:	246.1	.274
	898.2	1.000

REFLECTED (AT HIGHEST BEAM ORIENTATION)

BEAM COMPONENT:	92.1
DIFFUSE COMPONENT:	34.7
TOTAL REFLECTED:	126.8

ORIENTATION	BEAM/ HIGHEST BEAM	REFLECTED BEAM	REFLECTED DIFFUSE	REFLECTED TOTAL
0	.959	88.3	34.7	123.0
-35	1.000	92.1	34.7	126.8
-90	.789	72.6	34.7	107.3
-105	.605	55.8	34.7	90.5
-135	-	-	34.7	34.7
-165	-	-	34.7	34.7

C. AVERAGE DAILY RADIATION TRANSMITTED:

ORIENT.		INCID. RAD.	TRANS. FACTOR	TRANS. RAD.	GLASS AREA	TOT. RAD. TRANS.
0	BEAM	625.4	.601	375.9		
	DIFF	246.1	.608	149.6		
	REFL	123.0	.608	74.8		
	TOT			600.3	550	330,165
-35	BEAM	652.1	.632	412.1		
	DIFF	246.1	.608	149.6		
	REFL	126.8	.608	77.1		
	TOT			638.8	330	210,804
-90	BEAM	514.3	.613	315.3		
	DIFF	246.1	.608	149.6		
	REFL	107.3	.608	65.2		
	TOT			530.1	105	55,660
-105	BEAM	395.0	.601	237.4		
	DIFF	246.1	.608	149.6		
	REFL	90.5	.608	55.0		
	TOT			497.0	280	139,160
-135	BEAM	-	.472	-		
	DIFF	246.1	.608	149.6		
	REFL	34.7	.608	21.1		
	TOT			170.7	280	47,796
-165	BEAM	-	.163	-		
	DIFF	246.1	.608	149.6		
	REFL	34.7	.608	21.1		
	TOT			170.7	910	155,337
ROOF	BEAM	732.6	.149	109.2		
	DIFF	490.7	.608	72.1		
	REFL	.8	.608	.1		
	TOT			181.4	905	164,167
						1,103,089

D. MONTHLY AVERAGE TRANSMITTED RADIATION:

1,103,089 x 30 = 33,092,670 BTU/SEPTEMBER

E. SEPTEMBER MONTHLY LOAD:

BALANCE POINT:	54.4
DEGREE HOURS:	1,330.5
DEGREE DAYS:	55.4
BTU'S NEEDED IN SEPTEMBER:	2,935,520

F. NET SEPTEMBER SOLAR FRACTION:

33,092,670/2,935,520 = 1127.3%

G. GROSS SEPTEMBER SOLAR FRACTION:

33,092,670/(2,935,520 + 6,202,080) = 355.8%

OCTOBER

A. TRANSMITTED CLEAR DAY RADIATION:

ORIENTATION	INSOLATION					
	BEAM			DIFFUSE		
	TRANS	INC	FACTOR	TRANS	INC	FACTOR
0	855.6	1344.2	.637	110.4	181.6	.608
-35	698.8	1125.8	.621	"	"	"
-90	304.8	513.5	.594	"	"	"
-105	187.5	341.7	.549	"	"	"
-135	25.7	75.5	.340	"	"	"
-165	-	-	-	"	"	"
ROOF	109.8	828.6	.133	149.2	149.2	.147

B. CALCULATING REFLECTED RADIATION:

	INSOLATION	RATIO
HIGHEST AVERAGE DAY BEAM:	784.1	.810
AVERAGE DAY DIFFUSE:	183.9	.190
	968.0	1.000

REFLECTED (AT HIGHEST BEAM ORIENTATION)
BEAM COMPONENT: 72.7
DIFFUSE COMPONENT: 17.0
TOTAL REFLECTED: 89.7

ORIENTATION	BEAM/ HIGHEST BEAM	REFLECTED BEAM	REFLECTED DIFFUSE	TOTAL
0	1.000	72.7	17.0	89.7
-35	.880	64.0	17.0	81.0
-90	.502	36.5	17.0	53.5
-105	.317	23.0	17.0	40.0
-135	-	-	17.0	17.0
-165	-	-	17.0	17.0

C. AVERAGE DAILY RADIATION TRANSMITTED:

ORIENT.		INCID. RAD.	TRANS. FACTOR	TRANS. RAD.	GLASS AREA	TOT. RAD. TRANS.
0	BEAM	784.1	.637	499.5		
	DIFF	183.9	.608	111.8		
	REFL	89.7	.608	54.5		
	TOT			665.8	550	366,190
-35	BEAM	689.8	.621	428.4		
	DIFF	183.9	.608	111.8		
	REFL	81.0	.608	49.2		
	TOT			589.4	330	194,502
-90	BEAM	393.4	.594	233.7		
	DIFF	183.9	.608	111.8		
	REFL	53.5	.608	32.5		
	TOT			378.0	105	39,690
-105	BEAM	248.3	.340	136.3		
	DIFF	183.9	.068	111.8		
	REFL	40.0	.608	24.3		
	TOT			272.4	280	76,272
-135	BEAM	-	.340	-		
	DIFF	183.9	.608	111.8		
	REFL	17.0	.608	10.3		
	TOT			122.1	280	34,188
-165	BEAM	-	-	-		
	DIFF	183.9	.608	111.8		
	REFL	17.0	.608	10.3		
	TOT			122.1	910	111,111
ROOF	BEAM	478.4	.133	63.6		
	DIFF	366.6	.147	53.9		
	REFL	.6	.147	.1		
	TOT			117.6	905	106,428
						928,381

D. MONTHLY AVERAGE TRANSMITTED RADIATION:

928,381 x 31 = 28,779,811 BTU/OCTOBER

E. <u>OCTOBER MONTHLY LOAD</u>:

BALANCE POINT:	54.4
DEGREE HOURS:	4,493.2
DEGREE DAYS:	187.2
BTU'S NEEDED IN OCTOBER:	9,913,868

F. <u>NET OCTOBER SOLAR FRACTION</u>:

28,779,811/ 9,913,868 = 290.3%

G. <u>GROSS OCTOBER SOLAR FRACTION</u>:

28,779,811/(9,913,868 + 6,408,816) = 100.2%

NOVEMBER

A. TRANSMITTED CLEAR DAY RADIATION:

ORIENTATION	INSOLATION					
	BEAM			DIFFUSE		
	TRANS	INC	FACTOR	TRANS	INC	FACTOR
0	861.7	1316.0	.655	75.1	123.5	.608
-35	684.2	1076.8	.634	"	"	"
-90	195.7	350.5	.558	"	"	"
-105	95.8	194.2	.493	"	"	"
-135	2.8	13.6	.206	"	"	"
-165	-	-	-	"	"	"
ROOF	53.4	514.9	.104	15.5	105.3	.147

B. CALCULATING REFLECTED RADIATION:

	INSOLATION	RATIO
HIGHEST AVERAGE DAY BEAM:	626.6	.825
AVERAGE DAY DIFFUSE:	132.9	.155
	759.5	1.000

REFLECTED (AT HIGHEST BEAM ORIENTATION)

BEAM COMPONENT:	44.2
DIFFUSE COMPONENT:	9.4
TOTAL REFLECTED:	53.6

ORIENTATION	BEAM/ HIGHEST BEAM	BEAM	REFLECTED DIFFUSE	TOTAL
0	1.000	44.2	9.4	53.6
-35	.829	36.6	9.4	46.0
-90	.359	15.9	9.4	25.3
-105	.172	7.6	9.4	17.0
-135	-	-	9.4	9.4
-165	-	-	9.4	9.4

C. <u>AVERAGE DAILY RADIATION TRANSMITTED</u>:

ORIENT.		INCID. RAD.	TRANS. FACTOR	TRANS. RAD.	GLASS AREA	TOT. RAD. TRANS.
0	BEAM	626.6	.655	410.4		
	DIFF	132.9	.608	80.8		
	REFL	53.6	.608	32.6		
	TOT			523.8	550	288,090
-35	BEAM	519.4	.634	329.3		
	DIFF	132.9	.608	80.8		
	REFL	46.0	.608	28.0		
	TOT			438.1	330	144,573
-90	BEAM	225.0	.558	125.6		
	DIFF	132.9	.608	80.8		
	REFL	25.3	.608	15.4		
	TOT			221.8	105	23,289
-105	BEAM	107.7	.493	53.1		
	DIFF	132.9	.608	80.8		
	REFL	17.0	.608	10.3		
	TOT			144.2	280	40,376
-135	BEAM	-	.206	-		
	DIFF	132.9	.608	80.8		
	REFL	9.4	.608	5.7		
	TOT			86.5	280	24,220
-165	BEAM	-	-	-		
	DIFF	132.9	.608	80.8		
	REFL	9.4	.608	5.7		
	TOT			86.5	910	78,715
ROOF	BEAM	231.0	.104	24.0		
	DIFF	264.9	.147	38.9		
	REFL	.3	.147	-		
	TOT			62.9	905	56,924
						656,187

D. <u>MONTHLY AVERAGE TRANSMITTED RADIATION</u>:

656,187 x 30 = 19,685,610 BTU/NOVEMBER

E. <u>NOVEMBER MONTHLY LOAD</u>:

BALANCE POINT:	54.4
DEGREE HOURS:	9,596.6
DEGREE DAYS:	399.9
BTU'S NEEDED IN NOVEMBER:	21,174,035

F. <u>NET NOVEMBER SOLAR FRACTION</u>:

19,685,610/21,174,035 = 93.0%

G. <u>GROSS NOVEMBER SOLAR FRACTION</u>:

19,685,610/(21,174,035 + 6,202,080) = 71.4%

DECEMBER

A. TRANSMITTED CLEAR DAY RADIATION:

ORIENTATION	INSOLATION					
	BEAM			DIFFUSE		
	TRANS	INC	FACTOR	TRANS	INC	FACTOR
0	838.6	1280.3	.655	84.8	139.4	.068
-35	662.5	1039.1	.638	"	"	"
-90	167.8	294.0	.571	"	"	"
-105	75.7	147.6	.513	"	"	"
-135	-	.2	-	"	"	"
-165	-	-	-	"	"	"
ROOF	38.8	401.6	.097	13.0	88.6	.147

B. CALCULATING REFLECTED RADIATION:

	INSOLATION	RATIO
HIGHEST AVERAGE DAY BEAM:	681.6	.869
AVERAGE DAY DIFFUSE:	102.7	.131
	784.3	1.000

REFLECTED (AT HIGHEST BEAM ORIENTATION)

BEAM COMPONENT:	63.5
DIFFUSE COMPONENT:	9.6
TOTAL REFLECTED:	73.1

ORIENTATION	BEAM/ HIGHEST BEAM	REFLECTED BEAM	REFLECTED DIFFUSE	TOTAL
0	1.000	63.5	9.6	73.1
-35	.820	52.1	9.6	61.7
-90	.309	19.6	9.6	29.2
-105	.119	7.6	9.6	17.2
-135	-	-	9.6	9.6
-165	-	-	9.6	9.6

C. AVERAGE DAILY RADIATION TRANSMITTED:

ORIENT.		INCID. RAD.	TRANS. FACTOR	TRANS. RAD.	GLASS AREA	TOT. RAD. TRANS.
0	BEAM	681.6	.655	446.4		
	DIFF	102.7	.608	62.4		
	REFL	73.1	.608	44.4		
	TOT			553.2	550	304,260
-35	BEAM	559.1	.638	356.7		
	DIFF	102.7	.608	62.4		
	REFL	61.7	.608	37.5		
	TOT			456.6	330	150,678
-90	BEAM	210.7	.571	120.3		
	DIFF	102.7	.608	62.4		
	REFL	29.2	.608	17.8		
	TOT			190.5	105	20,002
-105	BEAM	81.1	.513	41.6		
	DIFF	102.7	.608	62.4		
	REFL	17.2	.608	10.5		
	TOT			114.5	280	32,060
-135	BEAM	-	-	-		
	DIFF	102.7	.608	62.4		
	REFL	9.6	.608	5.8		
	TOT			68.2	280	19,096
-165	BEAM	-	-	-		
	DIFF	102.7	.608	62.4		
	REFL	9.6	.608	5.8		
	TOT			68.2	910	62,062
ROOF	BEAM	195.6	.097	19.0		
	DIFF	204.7	.147	30.1		
	REFL	.5	.147	.1		
	TOT			49.2	905	44,526
						632,684

D. MONTHLY AVERAGE TRANSMITTED RADIATION:

632,684 x 31 = 19,613,204 BTU/DECEMBER

E. <u>DECEMBER MONTHLY LOAD</u>:

BALANCE POINT:	54.4
DEGREE HOURS:	19,784.2
DEGREE DAYS:	824.3
BTU'S NEEDED IN DECEMBER:	43,651,912

F. <u>NET DECEMBER SOLAR FRACTION</u>:

19,613,204/43,651,912 = 44.9 %

G. <u>GROSS DECEMBER SOLAR FRACTION</u>:

19,613,204/(943,651,912 + 6,408,816) = 39.2 %

13. CALCULATION OF 'SOUTH' GLAZING

MARCH:

TOT. CLEAR DAY TRANSMITTED RAD.	1,281,616
LESS RAD. FORM SOUTH FACING GLASS	481,800
	799,816

TO FIND EQUIV. AREA OF NON-SOUTH GLASS
DIVIDE BY RAD./SQ. FT. ON SOUTH GLASS

799,816/876.0 =	913
PLUS AREA OF SOUTH GLASS	550
	1463 SQ. FT

NOVEMBER:

TOT. CLEAR DAY TRANSMITTED RAD.	966,807
LESS RAD. FROM SOUTH FACING GLASS	515,240
	451,567

TO FIND EQUIV AREA OF NON-SOUTH GLASS
DIVIDE BY RAD./SQ. FT. oON SOUTH GLASS

451,567/936.9 =	482
PLUS AREA OF SOUTH GLASS	550
	1032 SQ. FT

(FIGURES USED IN STEPHEN HALE'S PROGRAM FOR CALCULATING OVERHEATING)

14. OVERHEATING

MARCH:

NOON TEMPERATURE UNVENTILATED 82.7 $^{\circ}$F.
2.00 P.M. UNVENTILATED 83.0

NOVEMBER:

NOON TEMPERATURE UNVENTILATED 79.4 $^{\circ}$F.
2.00 P.M. UNVENTILATED 81.0

(VENTILATED, THE TEMPERATURE IS THE SAME AS OUTDOORS)

APPENDIX 3 SUMMER INSTITUTE OUTLINE

The Summer Institute

The United States Department of Energy is sponsoring the **1979 Summer Institute on Energy and Design,** presented jointly by the AIA Research Corporation and the Association of Collegiate Schools of Architecture. The second annual Summer Institute will take place at the Massachusetts Institute of Technology in Cambridge, Massachusetts, from **12** to **17 August 1979.** Its major goal is to encourage the judicious use of energy in buildings through the strengthening of knowledge and concern about the relationships between energy and design in professional schools of architecture.

The Summer Institute can contribute to the achievement of this national goal by demonstrating that application of design principles to the practical problems of energy conservation in buildings is valuable, and that design responsive to the environment and to natural energy resources enriches the quality of architecture. It is important that architecture faculty become involved in working with these ideas, since the incorporation of energy conscious principles into design education will ultimately enhance the level of energy awareness in the future design profession. The Summer Institute provides such an opportunity for 40 faculty members from U.S. schools of architecture.

This year's Institute will be held at MIT, in Cambridge, Massachusetts. Attending faculty will be provided with housing on campus in McCormick Dormitory, a building with a beautiful roof terrace overlooking the Charles River and the Boston skyline. Participants will have exclusive use of McCormick Dorm during the Institute. University classrooms and studio space will also be provided. In addition, there will be enough free time for participants to enjoy the Boston metropolitan area, which is especially rich in architecture of various periods.

The Program

The 1979 Summer Institute is designed to serve as a gathering-place for architectural educators who wish to involve themselves in aspects of energy and design. Its program flows from a series of objectives which are as follows:

- to explore methods of design instruction which would facilitate the incorporation of energy conscious principles into the architectural education process;
- to give faculty an awareness of existing resources and their use;
- to encourage the application of this knowledge to each school's curriculum, and to provide faculty with the opportunity to develop teaching methods and strategies; and
- to identify useful design resources which are currently unavailable.

During the course of the Institute, a series of very specific energy-related topics will be considered in the context of architectural education.

Several of the areas to be investigated are daylighting, earth-sheltered structures, recently-developed building materials, energy analysis techniques, and life-cycle costing. Types of activities at the Institute will include lectures and presentations by experts in these fields, design studio activities, opportunities for hands-on experimentation with various tools and resources for energy conscious design, and organized field trips in the Boston-Cambridge area.

The particular talents and skills of each participant are crucial to this process of investigation and synthesis, and are among the most important resources at the Institute. Various recognized authorities in fields related to energy and design will also be present, to contribute to activities at the Institute.

Eligibility and Selection Criteria

Applications are invited from all United States professional degree-granting schools of architecture. Any faculty member who holds an appointment, either full- or part-time, on a faculty of architecture is eligible to apply for admission to the Summer Institute by following the application guidelines. Preference will be given to those faculty members who apply in two-person teams. However, interested faculty who apply individually will receive consideration as well. The emphasis on team participation is based on the conviction that a team can effectively influence the form of a curriculum within a school of architecture. Each team application should represent a combination of faculty expertise, specifically in the areas of design studio instruction and technical support courses. This particular combination is derived from the idea that the integration of technical information and skills into the design process can facilitate the incorporation of energy conscious principles into design education. Preference will also be given to applicants whose schools were not represented at the 1978 Summer Institute on Energy Conscious Design. No participant who attended last year is eligible for consideration this year. There is no restriction on the number of applications that will be considered from any single school; more than one design team from a school may apply. However, it is expected that only one team per school will be accepted.

Participant selection will be based upon the demonstration in the application of three qualifications: capability (skills and knowledge), the ability to effect subsequent changes within the institution, and commitment to the successful fulfillment of Summer Institute goals and program objectives.

Application Guidelines

Each application should consist of the following items:

An application form, to be completed by each individual applicant.

A summary sheet, to be completed for each team.

A current curriculum vitae for each applicant (not to exceed one page each).

A brief statement of purpose by each applicant, describing his or her reasons and specific qualifications for attendance at the Institute.

A letter of endorsement, to be completed by the department head or chairman for each applicant and included with the application.

Forty participants will be selected from the applications received. They will be expected to undertake preparatory work of approximately 20-25 hours prior to the Summer Institute.

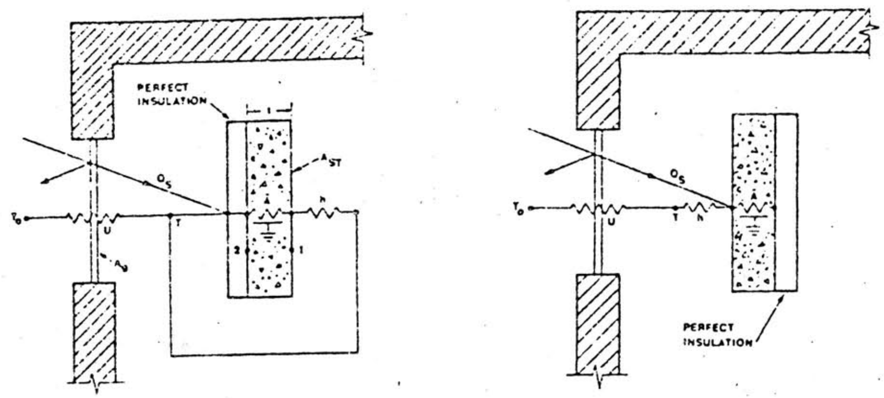
Interested faculty are encouraged to submit applications as soon as possible. The deadline for receipt of applications is **4 May 1979.** All applicants will be notified of selections by **15 May 1979.**

Applications should be sent to:

1979 Summer Institute on Energy and Design
Association of Collegiate Schools of Architecture
1735 New York Avenue, N.W.
Washington, D.C. 20006
(202) 387-7602

APPENDIX 4 TR-59 PROGRAMS

Temperature Swing Program



convective radiative

T.S.P. ©

TEMPERATURE SWING PROGRAM

This program predicts maximum and minimum temperatures for indirect and direct passive solar heating with an error of ± 15%. The product is two sets of temperature swings. The first, is typical of a configuration where the heat transfer of solar energy to storage mass is dominated by convective exchange. The second, is where transfer is dominated by radiative exchange(see Figures). Program limitations include ability to model only south facing solar glazing, and only concrete or plaster as a storage medium.[17] The method is based on equations established by P.W.B. Niles of California Polytechnic State University at San Luis Obispo, California.

METHOD

Step 0	Execute program on T.I.59 with printer.
Step 1	Read sides 1,2,3 of data card into calculator (559.49) partitioning)
Step 2	Input the following information:

STO	Location	Description	Units
	00	Average hourly internal gains	BTUH
	01	Indoor design temp. to be maintained	°F
"	02	Outdoor temp. (average over a 24 hr. period)	°F
"	03	House loss total minus losses through south glazing	
ditto		$= (U \times A_{total} - U \times A_{south\ glazing})$	BTUH/°F
"	04	Average daily insolation received inside bldg. divided by 24 hrs./per sq. ft. of glass (after transmission)	BTUH/ft^2
"	05	"U" value of south glazing	BTUH/ft^2 -°F
"	06	Outdoor temp. swing/2 over selected 24 hr. period	°F
"	07	Ratio of storage surface area divided by south glass area	--
"	08	Surface conductance of storage heavy wt. conc., plaster = 1	BTUH/ft^2 -°F
"	09	Period of daily temp. swing = constant 24	hrs.
"	10	Storage mass heat capacity per thickness specified (fraction of a foot) (conc. = 29.4)	BTU/F^2 - °F

(Temp. Swing Prog. - continued)

Location	Description	Units
11	Enter only if known - area of south glazing	Ft^2
12	House loss total (UA_{total})	BTUH/°F
13	Storage mass area	Ft^2

Step 3 Press: $\overline{\text{LBL}}$ $\overline{\text{A}}$ Use if south glass area is not known...............Program gives the area of south glass req'd. to achieve thermal equilibrium with environmental conditions given in storage locations 01-05. Continue to press $\overline{\text{LBL}}$ $\overline{\text{A}}$ until results close in on one number for square footage of South glass. Then, go for Step 4.

$\overline{\text{LBL}}$ $\overline{\text{B}}$ Use if glass area is known. This bypasses the glass area computation.

Step 4 Press: $\overline{\text{R/S}}$

Gives °F temp swing/2 when storage is dominated by convective coupling,

Then gives °F temp swing/2 when storage is dominated by radiative coupling,

Gives equilibrium temperature and resulting indoor air temperature for the two types of coupling.

(Temp. Swing Prog. - continued)

EXAMPLE

0.	Data based on measured data from M.I.T. Solar Demonstration Bldg. 5, Cambridge, Mass. Building is a direct gain system dominated by radiative coupling.		
1.	Ambient air temps	Min.	= 30° Max = 50
	Swing/2	20°/2	= 10°
2.	Tindoor swing	63°-76°	= 13° 69.5° ave. temp.
3.	House loss		= 240 BTUH/°F - [.18 x 180 SF = 32.4]
			= 207.6 BTUH/°F
			(total - south glass loss)
4.	Average solar insolation		= 175 BTU/SF @ noon ≈ 33 BTU/hr (over 24 hours)
5.		U_{glass}	= .18
6.	Effective storage surface area		= 400 SF
7.	Ratio of mass to glass		= 400/180 = 2.22
8.	Storage surface conductance		= 1.0 BTUH/SF • °F
9.	Storage mass heat capacity		= 22.5
10.	Given: south glass area		= 180 SF
11.	internal gains		= 1563 BTUH

(Temp. Swing Prog. - continued)

Enter Data	List Data		Results	
Press $\overline{B}$ since glass area is known	1563.	00	21.5	CONV
	69.5	01	6.59	RAD
	40.	02		
	207.6	03		
	33.	04	………………………	
	0.18	05		
	10.	06	71.26	°F
	2.22	07		
	1.	08	49.76	TD
	24.	09	92.76	
	22.5	10		
	180.	11		
	240.	12	64.67	TD
	400.	13	77.85	

Compare with Entry(2) in Example

Program Listing (printer version)

```
000  76 LBL
001  11  A
002  43 RCL
003  01  01
004  75  -
005  43 RCL
006  02  02
007  95  =
008  65  ×
009  43 RCL
010  03  03
011  95  =
012  42 STO
013  49  49
014  43 RCL
015  01  01
016  75  -
017  43 RCL
018  02  02
019  95  =
020  65  ×
021  43 RCL
022  05  05
023  95  =
024  42 STO
025  30  30
026  43 RCL
027  04  04
028  75  -
029  43 RCL
030  30  30
031  95  =
032  42 STO
033  46  46
034  02  2
035  01  1
036  03  3
037  07  7
038  07  7
039  00  0
040  69 OP
041  04  04
042  43 RCL
043  49  49
044  55  ÷
045  43 RCL
046  46  46
047  95  =
048  71 SBR
049  45 YX
050  42 STO
051  11  11
052  69 OP
053  06  06
054  43 RCL
055  12  12
056  75  -
057  53  (
058  43 RCL
059  11  11
060  65  ×
061  43 RCL
062  05  05
063  95  =
064  54  )
065  95  =
066  42 STO
067  03  03
068  43 RCL
069  13  13
070  55  ÷
071  43 RCL
072  11  11
073  95  =
074  42 STO
075  07  07
076  98 ADV
077  91 R/S
078  76 LBL
079  12  B
080  43 RCL
081  12  12
082  75  -
083  53  (
084  43 RCL
085  11  11
086  65  ×
087  43 RCL
088  05  05
089  95  =
090  54  )
091  95  =
092  42 STO
093  03  03
094  43 RCL
095  13  13
096  55  ÷
097  43 RCL
098  11  11
099  95  =
100  42 STO
101  07  07
102  43 RCL
103  03  03
104  55  ÷
105  43 RCL
106  11  11
107  95  =
108  85  +
109  43 RCL
110  05  05
111  95  =
112  42 STO
113  28  28
114  43 RCL
115  01  01
116  75  -
117  43 RCL
118  02  02
119  95  =
120  65  ×
121  01  1
122  93  .
123  06  6
124  06  6
125  06  6
126  95  =
127  33 X²
128  42 STO
129  15  15
130  43 RCL
131  06  06
132  33 X²
133  42 STO
134  48  48
135  43 RCL
136  01  01
137  75  -
138  43 RCL
139  02  02
140  95  =
141  65  ×
142  01  1
143  93  .
144  06  6
145  06  6
146  06  6
147  65  ×
148  43 RCL
149  06  06
150  65  ×
151  01  1
152  93  .
153  04  4
154  01  1
155  04  4
156  95  =
157  85  +
158  43 RCL
159  48  48
160  85  +
161  43 RCL
162  15  15
163  95  =
164  34 √X
165  42 STO
166  39  39
167  43 RCL
168  07  07
169  65  ×
170  43 RCL
171  08  08
172  95  =
173  55  ÷
174  43 RCL
175  28  28
```

```
176  95  =
177  85  +
178  02  2
179  95  =
180  65  X
181  43  RCL
182  07  07
183  65  X
184  43  RCL
185  08  08
186  95  =
187  55  ÷
188  43  RCL
189  28  28
190  95  =
191  42  STO
192  47  47
193  43  RCL
194  09  09
195  65  X
196  43  RCL
197  08  08
198  95  =
199  42  STO
200  45  45
201  43  RCL
202  10  10
203  65  X
204  06  6
205  93  .
206  02  2
207  08  8
208  03  3
209  95  =
210  42  STO
211  17  17
212  43  RCL
213  45  45
214  55  ÷
215  43  RCL
216  17  17
217  95  =
218  33  X²
219  85  +
220  01  1
221  95  =
222  42  STO
223  18  18
224  43  RCL
225  47  47
226  55  ÷
227  43  RCL
228  18  18
229  95  =
230  85  +
231  01  1
232  95  =
233  35  1/X
234  34  √X
235  95  =
236  42  STO
237  40  40
238  01  1
239  05  5
240  03  3
241  02  2
242  03  3
243  01  1
244  04  4
245  02  2
246  69  OP
247  04  04
248  43  RCL
249  39  39
250  65  X
251  43  RCL
252  40  40
253  95  =
254  71  SBR
255  45  YX
256  42  STO
257  41  41
258  69  OP
259  06  06
260  43  RCL
261  01  01
262  75  -
263  43  RCL
264  02  02
265  95  =
266  55  ÷
267  93  .
268  06  6
269  95  =
270  42  STO
271  29  29
272  06  6
273  93  .
274  02  2
275  08  8
276  03  3
277  65  X
278  43  RCL
279  10  10
280  95  =
281  42  STO
282  31  31
283  43  RCL
284  09  09
285  65  X
286  43  RCL
287  08  08
288  95  =
289  42  STO
290  32  32
291  43  RCL
292  31  31
293  55  ÷
294  43  RCL
295  32  32
296  95  =
297  85  +
298  01  1
299  95  =
300  65  X
301  43  RCL
302  06  06
303  95  =
304  65  X
305  01  1
306  93  .
307  04  4
308  01  1
309  04  4
310  95  =
311  85  +
312  43  RCL
313  29  29
314  95  =
315  42  STO
316  33  33
317  43  RCL
318  01  01
319  75  -
320  43  RCL
321  02  02
322  95  =
323  42  STO
324  34  34
325  06  6
326  93  .
327  02  2
328  08  8
329  03  3
330  65  X
331  43  RCL
332  10  10
333  95  =
334  42  STO
335  35  35
336  43  RCL
337  08  08
338  65  X
339  43  RCL
340  09  09
341  95  =
342  42  STO
343  36  36
344  43  RCL
345  35  35
346  55  ÷
347  43  RCL
348  36  36
349  95  =
350  33  X²
```

351	85	+	386	42	STO	421	04	4	456	54	)	491	69	OP	526	45	Y^X
352	01	1	387	42	42	422	00	0	457	55	÷	492	06	06	527	65	×
353	95	=	388	03	3	423	04	4	458	53	(	493	43	RCL	528	01	1
354	65	×	389	05	5	424	00	0	459	43	RCL	494	46	46	529	00	0
355	93	.	390	01	1	425	04	4	460	03	03	495	85	+	530	00	0
356	06	6	391	03	3	426	00	0	461	85	+	496	43	RCL	531	95	=
357	95	=	392	01	1	427	04	4	462	43	RCL	497	41	41	532	59	INT
358	42	STO	393	06	6	428	00	0	463	05	05	498	95	=	533	55	÷
359	37	37	394	69	OP	429	69	OP	464	65	×	499	99	PRT	534	01	1
360	43	RCL	395	04	04	430	01	01	465	43	RCL	500	98	ADV	535	00	0
361	34	34	396	43	RCL	431	69	OP	466	11	11	501	03	3	536	00	0
362	55	÷	397	41	41	432	02	02	467	54	)	502	07	7	537	95	=
363	43	RCL	398	55	÷	433	69	OP	468	85	+	503	03	3	538	92	RTN
364	37	37	399	43	RCL	434	03	03	469	43	RCL	504	02	2	539	91	R/S
365	95	=	400	39	39	435	69	OP	470	02	02	505	69	OP	540	91	R/S
366	42	STO	401	95	=	436	04	04	471	95	=	506	04	04	541	91	R/S
367	43	43	402	65	×	437	69	OP	472	71	SBR	507	43	RCL	542	91	R/S
368	43	RCL	403	43	RCL	438	05	05	473	45	Y^X	508	46	46	543	91	R/S
369	06	06	404	42	42	439	06	6	474	69	OP	509	75	-			
370	33	X^2	405	95	=	440	05	5	475	06	06	510	43	RCL			
371	95	=	406	71	SBR	441	02	2	476	98	ADV	511	45	45			
372	42	STO	407	45	Y^X	442	01	1	477	42	STO	512	95	=			
373	44	44	408	69	OP	443	69	OP	478	46	46	513	69	OP			
374	43	RCL	409	06	06	444	04	04	479	03	3	514	06	06			
375	43	43	410	42	STO	445	98	ADV	480	07	7	515	43	RCL			
376	65	×	411	45	45	446	53	(	481	03	3	516	46	46			
377	43	RCL	412	98	ADV	447	43	RCL	482	02	2	517	85	+			
378	33	33	413	06	6	448	04	04	483	69	OP	518	43	RCL			
379	95	=	414	05	5	449	65	×	484	04	04	519	45	45			
380	85	+	415	02	2	450	43	RCL	485	43	RCL	520	95	=			
381	43	RCL	416	01	1	451	11	11	486	46	46	521	99	PRT			
382	44	44	417	69	OP	452	85	+	487	75	-	522	98	ADV			
383	95	=	418	04	04	453	43	RCL	488	43	RCL	523	98	ADV			
384	34	√X	419	04	4	454	00	00	489	41	41	524	98	ADV			
385	95	=	420	00	0	455	95	=	490	95	=	525	76	LBL			

Average Daily Radiation Program

TITLE Average Daily Radiation PAGE ____ OF ____ **TI Programmable Program Record**

PROGRAMMER Jim Rosen DATE Jan. 23, 1979

Partitioning (Op 17) 7,1,9.2,9 Library Module any Printer Yes Cards 2

PROGRAM DESCRIPTION

Given a data base, this program calculates the average daily insolation for a surface of any orientation. This daily radiation is broken down into its beam, diffuse, and reflected components, in order to facilitate determining the quantity transmitted through a glazing system.

This program follows the method outlined by S.A. Klein in the enclosed article. The necessary data is all entered with the user defined labels. To re-run the program, only those data values that change need be re-entered. After entering the new data, press C' to run the program.

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
1	Partition calculator	3	OP	17		719.29
2	Read card sides 1, 2, 3, & 4	0				1,2,3,4
3	Enter tilt (90° = vertical)(s)	tilt	A			tilt
4	Enter azimuth angle (-east,+west)(γ)	azimuth	B			azimuth
5	Enter ground reflectance ($0 \leq \rho \leq 1$)	gr. refl.	C			gr. refl.
*6	Enter monthly average daily total	$\bar{H}$	D			$\bar{H}$
	radiation on horizontal surface.					
	(metric or english units), ($\bar{H}$)					
*7	Enter fraction of extraterrestrial	$\bar{K}_T$	E			$\bar{K}_T$
	radiation transmitted through the					
	atmosphere, ($\bar{K}_T$)					
8	Enter latitude, (ϕ)	latitude	A'			latitude
*9	Enter declination, (δ)	declination	B'			declination
10	Run program		C'			
	NON-PRINTER VERSION ONLY:					
10	Run program		C'			beam radiation
11	Run program		R/S			diffuse rad.
12	Run program		R/S			reflect. rad.
13	Run program		R/S			total rad.
	*values found in appendix					

USER DEFINED KEYS	DATA REGISTERS (INV LIST)	
A tilt	21 $\bar{H}$	
B azimuth	22 $\bar{K}_T$	
C ground reflect.	23 latitude	
D H	24 ground reflect.	
E K_T	25 tilt	
A' latitude	26 azimuth	
B' declination	27 declination	229
C' run program		

Jim Rosen
172 Fayerweather St.
Cambridge, MA 02138
(617) 661-3275

Sample data and output

1.	JAN	1.	JAN
43.	TILT	43.	TILT
0.	AZIM	15.	AZIM
0.2	REFL	0.2	REFL
6412.	AVE	6412.	AVE
0.485	%EXT	0.485	%EXT
43.	LAT	43.	LAT
-20.92	DECL	-20.92	DECL
10047.3	BEAM	9803.8	BEAM
2117.3	DIFF	2117.3	DIFF
172.3	REFL	172.3	REFL
12336.8	TOTL	12093.3	TOTL
2.	FEB	2.	FEB
9224.	AVE	9224.	AVE
0.496	%EXT	0.496	%EXT
-12.95	DECL	-12.95	DECL
11271.5	BEAM	11031.8	BEAM
2971.2	DIFF	2971.2	DIFF
247.8	REFL	247.8	REFL
14490.5	TOTL	14250.7	TOTL
3.	MARCH	3.	MARCH
13992.	AVE	13992.	AVE
0.543	%EXT	0.543	%EXT
-2.42	DECL	-2.42	DECL
13554.5	BEAM	13390.0	BEAM
4049.3	DIFF	4049.3	DIFF
375.9	REFL	375.9	REFL
17979.7	TOTL	17815.1	TOTL

MONTH NAME AND NUMBER WERE ENTERED MANUALLY

$Kj\ m^2 day^{-1}$

From: Klein, S.A., Calculation of Monthly Average Insolation on Tilted Surfaces., Solar Energy, Vol. 19 pp 328.

DECLINATION
(recommended values)

	Month	Value (degrees)
1	January	-20.92
2	February	-12.95
3	March	-2.42
4	April	9.41
5	May	18.79
6	June	23.09
7	July	21.18
8	August	13.45
9	September	2.22
10	October	-9.6
11	November	-18.91
12	December	-23.05

NOTE: $\overline{I}_H = \overline{H}$

Table A-4

Radiation and Other Data for 80 Locations in the United States

($\overline{I}_H$ Monthly average daily total radiation on a horizontal surface, Btu/day-ft^2; $\overline{K}_t$=the fraction of the extra terrestrial radiation transmitted through the atmosphere; t_o=average daytime ambient temperature, °F)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ALASKA													
Annette Is..............	$\overline{I}_H$	236.2	428.4	883.4	1357.2	1634.7	1638.7	1632.1	1269.4	962	454.6	220.3	152
Lat 55°02'N	$\overline{K}_t$	0.427	0.415	0.492	0.507	0.484	0.441	0.454	0.427	0.449	0.347	0.304	0.361
El. 110 ft..............	t_o	35.8	37.5	39.7	44.4	51.0	56.2	58.6	59.8	54.8	48.2	41.9	37.4
Barrow..................	$\overline{I}_H$	13.3	143.2	713.3	1491.5	1883	2055.3	1602.2	953.5	428.4	152.4	22.9	-
Lat. 71°20'N	$\overline{K}_t$	-	0.776	0.773	0.726	0.553	0.533	0.448	0.377	0.315	0.35	-	-
El. 22 ft.........	t_o	-13.2	-15.9	-12.7	2.1	20.5	35.4	41.6	40.0	31.7	18.6	2.6	-8.6
Bethel..................	$\overline{I}_H$	142.4	404.8	1052.4	1662.3	1711.8	1698.1	1401.8	938.7	755	430.6	164.9	83
Lat.60°47'N.............	$\overline{K}_t$	0.536	0.557	0.704	0.675	0.519	0.458	0.398	0.336	0.406	0.432	0.399	0.459
El. 125 ft..............	t_o	9.2	11.6	14.2	29.4	42.7	55.5	56.9	54.8	47.4	33.7	19.0	9.4
Fairbanks...............	$\overline{I}_H$	66	283.4	860.5	1481.2	1806.2	1970.8	1702.9	1247.6	699,6	323.6	104.1	20.3
Lat.64°49'N.............	$\overline{K}_t$	0.639	0.556	0.674	0.647	0.546	0.529	0.485	0.463	0.419	0.416	0.47	0.458
El. 436 ft..............	t_o	-7.0	0.3	13.0	32.2	50.5	62.4	63.8	58.3	47.1	29.6	5.5	-6.6
Matanuska...............	$\overline{I}_H$	119.2	345	-	1327.6	1628.4	1727.6	1526.9	1169	737.3	373.8	142.8	56.4
Lat.61°30'N.............	$\overline{K}_t$	0.513	0.503	-	0.545	0.494	0.466	0.434	0.419	0.401	0.390	0.372	0.36[illegible]
El. 180 ft..............	t_o	13.9	21.0	27.4	38.6	50.3	57.6	60.1	58.1	50.2	37.7	22.9	13.9
ALBERTA													
Edmonton................	$\overline{I}_H$	331.7	652.4	1165.3	1541.7	1900.4	1914.4	1964.9	1528	1113.3	704.4	413.6	245
Lat.53°35'N	$\overline{K}_t$	0.529	0.585	0.624	0.564	0.558	0.514	0.549	0.506	0.506	0.504	0.510	0.492
El. 2219 ft.............	t_o	10.4	14	26.3	42.9	55.4	61.3	66.6	63.2	54.2	44.1	26.7	14.0
ARKANSAS													
Little Rock.............	$\overline{I}_H$	704.4	974.2	1335.8	1669.4	1960.1	2091.5	2081.2	1938.7	1640.6	1282.6	913.6	701.1
Lat.34°44'N	$\overline{K}_t$	0.424	0.458	0.496	0.513	0.545	0.559	0.566	0.574	0.561	0.552	0.484	0.463
El. 265 ft..............	t_o	44.6	48.5	56.0	65.8	73.1	76.7	85.1	84.6	78.3	67.9	54.7	46.7
ARIZONA													
Phoenix.................	$\overline{I}_H$	1126.6	1514.7	1967.1	2388.2	2709.6	2781.5	2450.5	2299.6	2131.3	1688.9	1290	1040.9
Lat.33°26'N.............	$\overline{K}_t$	0.65	0.691	0.716	0.728	0.753	0.745	0.667	0.677	.722	0.708	0.657	0.652
El. 1112 ft.............	t_o	54.2	58.8	64.7	72.2	80.8	89.2	94.6	92.5	87.4	75.8	63.6	56.7
Tucson..................	$\overline{I}_H$	1171.9	1453.8	-	2434.7	-	2601.4	2292.2	2179.7	2122.5	1640.9	1322.1	1132.1
Lat. 32°07'N............	$\overline{K}_t$	0.648	0.646	-	0.738	-	0.698	0.625	0.640	0.710	0.672	0.650	0.679
El. 2556 ft.............	t_o	53.7	57.3	62.3	69.7	78,0	87.0	90.1	87.4	84.0	73.9	62.5	56.1
CALIFORNIA													
Davis...................	$\overline{I}_H$	599.2	945	1504	1959	2368.6	2619.2	2565.6	2287.8	1856.8	123[illegible].5	795.6	550.5
Lat. 38°33'N............	$\overline{K}_t$	0.416	0.490	0.591	0.617	0.662	0.697	0.697	0.637	0.664	0.598	0.477	0.421
El. 51 ft...............	t_o	47.6	52.1	56.8	63.1	69.6	75.7	81	79.4	76.7	67.8	57	48.7
Fresno..................	$\overline{I}_H$	712.9	1116.6	1652.8	2049.4	2409.2	2641.7	2512.2	2300.7	1897.8	1415.5	906.6	616.6
Lat. 36°46'N............	$\overline{K}_t$	0.462	0.551	0.632	0.638	0.672	0.703	0.682	0.686	0.665	0.635	0.512	0.44
El. 331 ft..............	t_o	47.3	53.9	59.1	65.6	73.5	80.7	87.5	84.9	78.6	68.7	57.3	48.9
Inyokern................	$\overline{I}_H$	1148.7	1554.2	2136.9	2594.8	2925.4	3108.8	2908.8	2759.4	2409.2	1819.2	3170.1	1094.4
Lat. 35° 39'N...........	$\overline{K}_t$	0.716	0.745	0.803	0.8	0.815	0.830	0.790	0.820	0.834	0.795	0.743	0.742
El. 2440 ft.............	t_o	47.3	53.9	59.1	65.6	73.5	80.7	87.5	84.9	78.6	68.7	57.3	48.9
Los Angeles, (WBO)......	$\overline{I}_H$	911.8	1223.6	1640.9	1866.8	2061.2	2259	2428.4	2198.9	1891.5	1362.3	1053.1	877.8
Lat.34°03'N	$\overline{K}_t$	0.538	0.568	0.602	0.571	0.573	0.605	0.66	0.648	0.643	0.578	0.548	0.566
El. 99 ft...............	t_o	57.9	59.2	61.8	64.3	67.6	70.7	75.8	76.1	74.2	69.6	65.4	60.2
Los Angeles, (WBAS)	$\overline{I}_H$	930.6	1284.1	1729.5	1948	2196.7	2272.3	2413.6	2155.3	1898.1	1372.7	1082.3	901.1
Lat. 33°56'N............	$\overline{K}_t$	0.547	0.596	0.635	0.595	0.610	0.608	0.657	0.635	0.641	0.574	0.551	0.566
El. 99 ft...............	t_o	56.2	56.9	59.2	61.4	64.2	66.7	69.6	70.2	69.1	66.1	62.6	58.7
Riverside...............	$\overline{I}_H$	999.6	1335	1750.5	1943.2	2282.3	2492.6	2443.5	2263.8	1955.3	1509.6	1169	979.7
Lat. 33°57'N............	$\overline{K}_t$	0.589	0.617	0.643	0.594	0.635	0.667	0.665	0.668	0.665	0.639	0.606	0.626
El. 1020 ft.............	t_o	55.3	57.0	60.6	65.0	69.4	74.0	81.0	81.0	78.5	71.0	63.1	57.2
Santa Maria.............	$\overline{I}_H$	983.8	1296.3	1805.9	2067.9	2375.6	2599.6	2540.6	2293.3	1965.7	1566.4	1169	943.9
Lat. 34°54'N............	$\overline{K}_t$	0.595	0.613	0.671	0.636	0.661	0.695	0.690	0.678	0.674	0.676	0.624	0.627
El. 238 ft..............	t_o	54.1	55.3	57.6	59.5	61.2	63.5	65.3	65.7	65.9	64.1	60.8	56.1
COLORADO													
Grand Junction..........	$\overline{I}_H$	848	1210.7	1622.9	2002.2	2300.3	2645.4	2517.7	2157.2	1957.5	1394.8	969.7	793.4
Lat. 39°07'N............	$\overline{K}_t$	0.597	0.633	0.643	0.632	0.643	0.704	0.690	0.65	0.705	0.654	0.59	0.621
El. 4849 ft.............	t_o	26.9	35.0	44.6	55.8	66.3	75.7	82.5	79.6	71.4	58.3	42.0	31.4
Grand Lake............	$\overline{I}_H$	735	1135.4	1579.3	1876.7	1974.9	2369.7	2103.3	1708.5	1715.8	1212.2	775.6	660.5
Lat. 40°15'N..........	$\overline{K}_t$	0.541	0.615	0.637	0.597	0.553	0.63	0.572	0.516	0.626	0.583	0.494	0.542
El. 8389 ft...........	t_o	18.5	23.1	28.5	39.1	48.7	56.6	62.8	61.5	55.5	45.2	30.3	22.6

From: Applications of Solar Energy for Heating and Cooling of Buildings, ASHRAE [17]

Table A-4 (Continued)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
DISTRICT OF COLUMBIA													
Washington (WBCO).......	$\overline{I}_H$	632.4	901.5	1255	1600.4	1846.8	2080.8	1929.9	1712.2	1446.1	1083.4	763.5	594.1
Lat. 38°51'N............	$\overline{K}_t$	0.445	0.470	0.496	0.504	0.516	0.553	0.524	0.516	0.520	0.506	0.464	0.460
El. 64 ft...............	t_o	38.4	39.6	48.1	57.5	67.7	76.2	79.9	77.9	72.2	60.9	50.2	40.2
FLORIDA													
Apalachicola............	$\overline{I}_H$	1107	1378.2	1654.2	2040.9	2268.6	2195.9	1978.6	1912.9	1703.3	1544.6	1243.2	982.3
Lat. 29°45'N............	$\overline{K}_t$	0.577	0.584	0.576	0.612	0.630	0.594	0.542	0.558	0.559	0.608	0.574	0.543
El. 35 ft...............	t_o	57.3	59.0	62.9	69.5	76.4	81.8	83.1	83.1	80.6	73.2	63.7	58.55
Gainesville.............	$\overline{I}_H$	1036.9	1324.7	1635	1956.4	1934.7	1960.9	1895.6	1873.8	1615.1	1312.2	1169.7	919.5
Lat. 29°39'N............	$\overline{K}_t$	0.535	0.56	0.568	0.587	0.538	0.531	0.519	0.547	0.529	0.515	0.537	0.508
El. 165 ft..............	t_o	62.1	63.1	67.5	72.8	79.4	83.4	83.8	84.1	82	75.7	67.2	62.4
Miami...................	$\overline{I}_H$	1292.2	1554.6	1828.8	2020.6	2068.6	1991.5	1992.6	1890.8	1646.8	1436.5	1321	1183.4
Lat. 25°47'N............	$\overline{K}_t$	0.604	0.616	0.612	0.600	0.578	0.545	0.552	0.549	0.525	0.534	0.559	0.588
El. 9 ft................	t_o	71.6	72.0	73.8	77.0	79.9	82.9	84.1	84.5	83.3	80.2	75.6	72.6
Tampa...................	$\overline{I}_H$	1223.6	1461.2	1771.9	2016.2	2228	2146.5	1991.9	1845.4	1687.8	1493.3	1328.4	1119.5
Lat. 27°55'N............	$\overline{K}_t$	0.605	0.600	0.606	0.602	0.620	0.583	0.548	0.537	0.546	0.572	0.590	0.589
El. 11 ft...............	t_o	64.2	65.7	68.8	74.3	79.4	83.0	84.0	84.4	82.9	77.2	69.6	65.5
GEORGIA													
Atlanta.................	$\overline{I}_H$	848	1080.1	1426.9	1807	2618.1	2002.6	2002.9	1898.1	1519.2	1290.8	997.8	751.[illegible]
Lat. 33°39'N............	$\overline{K}_t$	0.493	0.496	0.522	0.551	0.561	0.564	0.545	0.559	0.515	0.543	0.510	0.474
El. 976 ft..............	t_o	47.2	49.6	55.9	65.0	73.2	80.9	82.4	81.6	77.4	66.5	54.8	47.7
Griffin.................	$\overline{I}_H$	889.6	1135.8	1450.9	1923.6	2163.1	2176	2064.9	1961.2	1605.9	1352.4	1073.8	781.5
Lat. 33°15'N............	$\overline{K}_t$	0.513	0.517	0.528	0.586	0.601	0.583	0.562	0.578	0.543	0.565	0.545	0.487
El. 980 ft..............	t_o	48.9	51.0	59.1	66.7	74.6	81.2	83.0	82.2	78.4	68	57.3	49.4
IDAHO													
Boise...................	$\overline{I}_H$	518.8	884.9	1280.6	1814.4	2189.3	2376.7	2500.3	2149.4	1717.7	1128.4	678.6	436.8
Lat. 43°34'N............	$\overline{K}_t$	0.446	0.533	0.548	0.594	0.619	0.631	0.684	0.660	0.656	0.588	0.494	0.442
El. 2844 ft.............	t_o	29.5	36.5	45.0	53.5	62.1	69.3	79.6	77.2	66.7	56.3	42.3	33.1
ILLINOIS													
Lemont..................	$\overline{I}_H$	(590)	879	1255.7	1481.5	1866	2041.7	1990.8	1836.9	1469.4	1015.5	(639)	(531)
Lat. 41°40'N............	$\overline{K}_t$	(0.464)	0.496	0.520	0.477	0.525	0.542	0.542	0.559	0.547	0.506	(0.433)	(0.467)
El 595 ft...............	t_o	28.9	30.3	39.5	49.7	59.2	70.8	75.6	74.3	67.2	57.6	43.0	30.6
INDIANA													
Indianapolis............	$\overline{I}_H$	526.2	797.4	1184.1	1481.2	1828	2042	2039.5	1832.1	1513.3	1094.4	662.4	491.1
Lat. 39°44'N............	$\overline{K}_t$	0.380	0.424	0.472	0.47	0.511	0.543	0.554	0.552	0.549	0.520	0.413	0.391
El. 793 ft..............	t_o	31.3	33.9	43.0	54.1	64.9	74.8	79.6	77.4	70.6	59.3	46.2	33.4
KANSAS													
Dodge City..............	$\overline{I}_H$	953.1	1186.3	1565.7	1975.6	2126.5	2459.8	2400.7	2210.7	1841.7	1421	1065.3	873.8
Lat. 37°46'N............	$\overline{K}_t$	0.639	0.598	0.606	0.618	0.594	0.655	0.652	0.663	0.654	0.650	0.625	0.652
El. 2592 ft.............	t_o	33.8	38.7	46.5	57.7	66.7	77.2	83.8	82.4	73.7	61.7	46.5	36.8
KENTUCKY													
Lexington...............	$\overline{I}_H$	-	-	-	1834.7	2171.2	-	2246.5	2064.9	1775.6	1315.8	-	681.5
Lat. 38°02'N............	$\overline{K}_t$	-	-	-	0.575	0.606	-	0.610	0.619	0.631	0.604	-	0.513
El. 979 ft..............	t_o	36.5	38.8	47.4	57.8	67.5	76.2	79.8	78.2	72.8	61.2	47.6	38.5
LOUISIANA													
Lake Charles............	$\overline{I}_H$	899.2	1145.7	1487.4	1801.8	2080.4	2213.3	1968.6	1910.3	1678.2	1505.5	1122.1	875.6
Lat. 30°13'N.	$\overline{K}_t$	0.473	0.492	0.521	0.542	0.578	0.597	0.538	0.558	0.553	0.597	0.524	0.494
El. 12 ft......	t_o	55.3	58.7	63.5	70.9	77.4	83.4	84.8	85.0	81.5	73.8	62.6	56.9
MAINE													
Caribou.................	$\overline{I}_H$	497	861.6	1360.1	1495.9	1779.7	1779.7	1898.1	1675.6	1254.6	793	415.5	398.9
Lat. 46°52'N............	$\overline{K}_t$	0.504	0.579	0.619	0.507	0.509	0.473	0.522	0.527	0.506	0.455	0.352	0.470
El. 628 ft..............	t_o	11.5	12.8	24.4	37.3	51.8	61.6	67.2	65.0	56.2	44.7	31.3	16.8
Portland................	$\overline{I}_H$	565.7	874.5	1329.5	1528.4	1923.2	2017.3	2095.6	1799.2	1428.8	1035	591.5	507.7
Lat. 43°39'N............	$\overline{K}_t$	0.482	0.524	0.569	0.500	0.544	0.536	0.572	0.554	0.546	0.539	0.431	0.491
El. 63 ft...............	t_o	23.7	24.5	34.4	44.8	55.4	65.1	71.1	69.7	61.9	51.8	40.3	28.0
MANITOBA													
Winnipeg................	$\overline{I}_H$	488.2	835.4	1354.2	1641.3	1904.4	1962	212[illegible].6	1761.2	1190.4	767.5	444.6	345.[illegible]
Lat. 49°54'N............	$\overline{K}_t$	0.601	0.636	0.661	0.574	0.550	0.524	0.587	0.567	0.504	0.482	0.436	0.503
El. 786 ft..............	t_o	3.2	7.1	21.3	40.9	55.9	65.3	71.9	69.4	58.6	45.6	25.2	10.1
MASSACHUSETTS													
Blue Hill...............	$\overline{I}_H$	555.3	797	1143.9	1439	1776.4	1943.9	1881.5	1622.1	1314	941	592.2	482.3
Lat. 42°13'N............	$\overline{K}_t$	0.445	0.458	0.477	0.464	0.501	0.516	0.513	0.495	0.492	0.472	0.406	0.436
El. 629 ft..............	t_o	28.3	28.3	36.9	46.9	58.5	67.2	72.5	70.6	64.2	54.1	43.3	31.5
Boston..................	$\overline{I}_H$	505.5	738	1067.1	1355	1769	1864	1860.5	1570.1	1267.5	896.7	535.3	442.8
Lat. 42°22'N............	$\overline{K}_t$	0.410	0.426	0.445	0.438	0.499	0.495	0.507	0.480	0.477	0.453	0.372	0.400
El. 29 ft...............	t_o	31.4	31.4	39.9	49.5	60.4	69.8	74.5	73.8	66.8	57.4	46.6	34.9

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Table A-4 (Continued)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MASSACHUSETTS (Contd.)													
East Wareham............	$\bar{I}_H$	504.4	762.4	1132.1	1392.6	1704.8	1958.3	1873.8	1607.4	1363.8	996.7	636.2	521
Lat. 41°46'N............	$\bar{K}_t$	0.398	0.431	0.469	0.449	0.480	0.520	0.511	0.489	0.508	0.496	0.431	0.461
El. 18 ft...............	t_o	32.2	31.6	39.0	48.3	58.9	67.5	74.1	72.8	65.9	56	46	34.8
MICHIGAN													
East Lansing............	$\bar{I}_H$	425.8	739.1	1086	1249.8	1732.8	1914	1884.5	1627.7	1303.3	891.5	473.1	379.7
Lat. 42°44'N............	$\bar{K}_t$	0.35	0.431	0.456	0.406	0.489	0.508	0.514	0.498	0.493	0.456	0.333	0.349
El. 856 ft..............	t_o	26.0	26.4	35.7	48.4	59.8	70.3	74.5	72.4	65.0	53.5	40.0	29.0
Sault Ste. Marie........	$\bar{I}_H$	488.6	843.9	1336.5	1559.4	1962.3	2064.2	2149.4	1767.9	1207	809.2	392.2	359.8
Lat. 46°28'N............	$\bar{K}_t$	0.490	0.560	0.606	0.526	0.560	0.549	0.590	0.554	0.481	0.457	0.323	0.408
El. 724 ft..............	t_o	16.3	16.2	25.6	39.5	52.1	61.6	67.3	66.0	57.9	46.8	33.4	21.9
MINNESOTA													
St. Cloud...............	$\bar{I}_H$	632.8	976.7	1383	1598.1	1859.4	2003.3	2087.8	1828.4	1369.4	890.4	545.4	463.1
Lat. 45°35'N............	$\bar{K}_t$	0.595	0.629	0.614	0.534	0.530	0.533	0.573	0.570	0.539	0.490	0.435	0.504
El. 1034 ft.............	t_o	13.6	16.9	29.8	46.2	58.8	68.5	74.4	71.9	62.5	50.2	32.1	18.3
MISSOURI													
Columbia................	$\bar{I}_H$	651.3	941.3	1315.8	1631.3	1999.6	2129.1	2148.7	1953.1	1689.6	1202.6	839.5	590.4
Lat. 38°58IN............	$\bar{K}_t$	0.458	0.492	0.520	0.514	0.559	0.566	0.585	0.588	0.606	0.562	0.510	0.457
El. 785 ft..............	t_o	32.5	36.5	45.9	57.7	66.7	75.9	81.1	79.4	71.9	61.4	46.1	35.8
MONTANA													
Glasgow.................	$\bar{I}_H$	572.7	965.7	1437.6	1741.3	2127.3	2261.6	2414.7	1984.5	1531	997	574.9	428.4
Lat. 48°13'N............	$\bar{K}_t$	0.621	0.678	0.672	0.597	0.611	0.602	0.666	0.630	0.629	0.593	0.516	0.548
El. 2277 ft.............	t_o	13.3	17.3	31.1	47.8	59.3	67.3	76	73.2	61.2	49.2	31.0	18.6
Great Falls.............	$\bar{I}_H$	524	869.4	1369.7	1621.4	1970.8	2179.3	2383	1986.3	1536.5	984.9	575.3	420.7
Lat. 47°29'N............	$\bar{K}_t$	0.552	0.596	0.631	0.551	0.565	0.580	0.656	0.627	0.626	0.574	0.503	0.518
El. 3664 ft.............	t_o	25.4	27.6	35.6	47.7	57.5	64.3	73.8	71.3	60.6	51.4	38.0	29.1
NEBRASKA													
Lincoln.................	$\bar{I}_H$	712.5	955.7	1299.6	1587.8	1856.1	2040.6	2011.4	1902.6	1543.5	1215.8	773.4	643.2
Lat. 40°51'N............	$\bar{K}_t$	0.542	0.528	0.532	0.507	0.522	0.542	0.547	0.577	0.568	0.596	0.508	0.545
El. 1189 ft.............	t_o	27.8	32.1	42.4	55.8	65.8	76.0	82.6	80.2	71.5	59.9	43.2	31.8
NEVADA													
Ely.....................	$\bar{I}_H$	871.6	1255	1749.8	2103.3	2322.1	2649	2417	2307.7	1935	1473	1078.6	814.8
Lat. 39°17'N............	$\bar{K}_t$	0.618	0.660	0.692	0.664	0.649	0.704	0.656	0.695	0.696	0.691	0.658	0.64
El. 6262 ft.............	t_o	27.3	32.1	39.5	48.3	57.0	65.4	74.5	72.3	63.7	52.1	39.9	31.1
Las Vegas...............	$\bar{I}_H$	1035.8	1438	1926.5	2322.8	2629.5	2799.2	2524	2342	2062	1602.6	1190	964.2
Lat. 36°05'N............	$\bar{K}_t$	0.654	0.697	0.728	0.719	0.732	0.746	0.685	0.697	0.716	0.704	0.657	0.668
El. 2162 ft.............	t_o	47.5	53.9	60.3	69.5	78.3	88.2	95.0	92.9	85.4	71.7	57.8	50.2
NEW JERSEY													
Seabrook................	$\bar{I}_H$	591.9	854.2	1195.6	1518.8	1800.7	1964.6	1949.8	1715	1445.7	1071.9	721.8	522.5
Lat. 39°30'N............	$\bar{K}_t$	0.426	0.453	0.476	0.481	0.504	0.522	0.530	0.517	0.524	0.508	0.449	0.416
El. 100 ft..............	t_o	39.5	37.6	43.9	54.7	64.9	74.1	79.8	77.7	69.7	61.2	48.5	39.3
NEW MEXICO													
Albuquerque.............	$\bar{I}_H$	1150.9	1453.9	1925.4	2343.5	2560.9	2757.5	2561.2	2387.8	2120.3	1639.8	1274.2	1051.6
Lat. 35°03'N............	$\bar{K}_t$	0.704	0.691	0.719	0.722	0.713	0.737	0.695	0.708	0.728	0.711	0.684	0.704
El. 5314 ft.............	t_o	37.3	43.3	50.1	59.6	69.4	79.1	82.8	80.6	73.6	62.1	47.8	39.4
NEW YORK													
Ithaca..................	$\bar{I}_H$	434.3	755	1074.9	1322.9	1779.3	2025.8	2031.3	1736.9	1320.3	918.4	466.4	370.8
Lat. 42°27'N............	$\bar{K}_t$	0.351	0.435	0.45	0.428	0.502	0.538	0.554	0.530	0.497	0.465	0.324	0.337
El. 950 ft..............	t_o	27.2	26.5	36	48.4	59.6	68.9	73.9	71.9	64.2	53.6	41.5	29.6
New York................	$\bar{I}_H$	539.5	790.8	1180.4	1426.2	1738.4	1994.3	1938.7	1605.9	1349.4	977.8	598.1	476
Lat. 40°46'N............	$\bar{K}_t$	0.406	0.435	0.480	0.455	0.488	0.53	0.528	0.486	0.500	0.475	0.397	0.403
El. 52 ft...............	t_o	35.0	34.9	43.1	52.3	63.3	72.2	76.9	75.3	69.5	59.3	48.3	37.7
Sayville................	$\bar{I}_H$	602.9	936.2	1259.4	1560.5	1857.2	2123.2	2040.9	1734.7	1446.8	1087.4	697.8	533.9
Lat. 40°30'N............	$\bar{K}_t$	0.453	0.511	0.510	0.498	0.522	0.564	0.555	0.525	0.530	0.527	0.450	0.447
El. 20 ft...............	t_o	35	34.9	43.1	52.3	63.3	72.2	76.9	75.3	69.5	59.3	48.3	37.7
Schenectady.............	$\bar{I}_H$	488.2	751.5	1026.6	1272.3	1553.1	1687.8	1662.3	1494.8	1124.7	820.6	436.2	356.8
Lat. 42°50'N............	$\bar{K}_t$	0.406	0.441	0.433	0.413	0.438	0.448	0.454	0.458	0.426	0.420	0.309	0.331
El. 217 ft..............	t_o	24.7	24.6	34.9	48.3	61.7	70.8	76.9	73.7	64.6	53.1	40.1	28.0
Upton...................	$\bar{I}_H$	583	872.7	1280.4	1609.9	1891.5	2159	2044.6	1789.6	1472.7	1102.6	686.7	551.3
Lat. 40°52'N............	$\bar{K}_t$	0.444	0.483	0.522	0.514	0.532	0.574	0.557	0.542	0.542	0.538	0.448	0.467
El. 75 ft...............	t_o	35.0	34.9	43.1	52.3	63.3	72.2	76.9	75.3	69.5	59.3	48.3	37.7
NORTH CAROLINA													
Greensboro..............	$\bar{I}_H$	743.9	1031.7	1321.2	1755.3	1988.5	2111.4	2033.9	1810.3	1517.3	1202.6	908.1	690.8
Lat. 36°05'N............	$\bar{K}_t$	0.469	0.499	0.499	0.543	0.554	0.563	0.552	0.538	0.527	0.531	0.501	0.479
El. 891 ft..............	t_o	42.0	44.2	41.7	60.8	69.9	78.0	80.2	78.9	73.9	62.7	51.5	43.2

Table A-4 (Continued)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NORTH CAROLINA (Contd.)													
Hatteras..............	$\bar{I}_H$	891.9	1184.1	1590.4	2128	2376.4	2438	2334.3	2085.6	1758.3	1337.6	1053.5	798.1
Lat. 35°13'N..........	K_t	0.546	0.563	0.593	0.655	0.661	0.652	0.634	0.619	0.605	0.58	0.566	0.535
El 7 ft...............	t_o	49.9	49.5	54.7	61.5	69.9	77.2	80.0	79.8	76.7	67.9	59.1	51.3
NORTH DAKOTA													
Bismarck..............	$\bar{I}_H$	587.4	934.3	1328.4	1668.2	2056.1	2173.8	2305.5	1929.1	1441.3	1018.1	600.4	464.2
Lat. 46°47'N..........	K_t	0.594	0.628	0.605	0.565	0.588	0.579	0.634	0.606	0.581	0.584	0.510	0.547
El. 1660 ft...........	t_o	12.4	15.9	29.7	46.6	58.6	67.9	76.1	73.5	61.6	49.6	31.4	18.4
OHIO													
Cleveland.............	$\bar{I}_H$	466.8	681.9	1207	1443.9	1928.4	2102.6	2094.4	1840.6	1410.3	997	526.6	427.3
Lat. 41°24'N..........	K_t	0.361	0.383	0.497	0.464	0.543	0.559	0.571	0.559	0.524	0.491	0.351	0.371
El.805 ft.............	t_o	30.8	30.9	39.4	50.2	62.4	72.7	77.0	75.1	68.5	57.4	44.0	32.8
Columbus..............	$\bar{I}_H$	486.3	746.5	1112.5	1480.8	1839.1	(2111)	2041.3	1572.7	1189.3	919.5	479	430.2
Lat. 40°00'N..........	K_t	0.356	0.401	0.447	0.470	0.515	(0.561)	0.555	0.475	0.433	0.441	0.302	0.351
El. 833 ft............	t_o	32.1	33.7	42.7	53.5	64.4	74.2	78	75.9	70.1	58	44.5	34.0
OKLAHOMA													
Oklahoma City.........	$\bar{I}_H$	938	1192.6	1534.3	1849.4	2005.1	2355	2273.8	2211	1819.2	1409.6	1085.6	897.4
Lat. 35°24'N..........	K_t	0.580	0.571	0.576	0.570	0.558	0.629	0.618	0.565	0.628	0.614	0.588	0.608
El. 1304 ft...........	t_o	40.1	45.0	53.2	63.6	71.2	80.6	85.5	85.4	77.4	66.5	52.2	43.1
Stillwater............	$\bar{I}_H$	763.8	1081.5	1463.8	1702.6	1879.3	2235.8	2224.3	2039.1	1724.3	1314	991.5	783
Lat. 36°09'N..........	K_t	0.484	0.527	0.555	0.528	0.523	0.596	0.604	0.607	0.599	0.581	0.548	0.544
El. 910 ft............	t_o	41.2	45.6	53.8	64.2	71.6	81.1	85.9	85.9	77.5	67.6	52.6	43.9
ONTARIO													
Ottawa................	$\bar{I}_H$	539.1	852.4	1250.5	1506.6	1857.2	2084.5	2043.4	1752.4	1326.6	826.9	458.7	408.5
Lat. 45°20'N..........	K_t	0.499	0.540	0.554	0.502	0.529	0.534	0.560	0.546	0.521	0.430	0.359	0.436
El. 339 ft............	t_o	14.6	15.6	27.7	43.3	57.5	67.5	71.9	69.8	61.5	48.9	35	19.6
Toronto...............	$\bar{I}_H$	451.3	674.5	1088.9	1388.2	1785.2	1941.7	1968.6	1622.5	1284.1	835	458.3	352.8
Lat. 43°41'N..........	K_t	0.388	0.406	0.467	0.455	0.506	0.516	0.539	0.500	0.493	0.438	0.336	0.346
El. 379 ft............	t_o	26.5	26.0	34.2	46.3	58	68.4	73.8	71.8	64.3	52.6	40.9	30.2
OREGON													
Astoria...............	$\bar{I}_H$	338.4	607	1008.5	1401.5	1838.7	1753.5	2007.7	1721	1322.5	780.4	413.6	295.2
Lat. 46°12'N..........	K_t	0.330	0.397	0.454	0.471	0.524	0.466	0.551	0.538	0.526	0.435	0.336	0.332
El. 8 ft..............	t_o	41.3	44.7	46.9	51.3	55.0	59.3	62.6	63.6	62.2	55.7	48.5	43.9
Medford...............	$\bar{I}_H$	435.4	804.4	1259.8	1807.4	2216.2	2440.5	2607.4	2261.6	1672.3	1043.5	558.7	346.5
Lat. 42°23'N..........	K_t	0.353	0.464	0.527	0.584	0.625	0.648	0.710	0.689	0.628	0.526	0.354	0.313
El. 1329 ft...........	t_o	39.4	45.4	50.8	56.3	63.1	69.4	76.9	76.4	69.6	58.7	47.1	40.5
PENNSYLVANIA													
State College.........	$\bar{I}_H$	501.8	749.1	1106.6	1399.2	1754.6	2027.6	1968.2	1690	1336.1	1017	580.1	4443.9
Lat. 40°48'N..........	K_t	0.381	0.413	0.451	0.448	0.493	0.539	0.536	0.512	0.492	0.496	0.379	0.376
El. 1175 ft...........	t_o	31.3	31.4	39.8	51.3	63.4	71.8	75.8	73.4	66.1	55.6	43.2	32.6
RHODE ISLAND													
New Port..............	$\bar{I}_H$	565.7	856.4	1231.7	1484.8	1849	2019.2	1942.8	1687.1	1411.4	1035.4	656.1	527.7
Lat. 41°29'N..........	K_t	0.438	0.482	0.507	0.477	0.520	0.536	0.529	0.513	0.524	0.512	0.44	0.460
El. 60 ft.............	t_o	29.5	32.0	39.6	48.2	58.6	67.0	73.2	72.3	66.7	56.2	46.5	34.4
SOUTH CAROLINA													
Charleston............	$\bar{I}_H$	946.1	1152.8	1352.4	1918.8	2063.4	2113.3	1649.4	1933.6	1557.2	1332.1	1073.8	952
Lat. 32°54'N..........	K_t	0.541	0.521	0.491	0.584	0.574	0.567	0.454	0.569	0.525	0.554	0.539	0.586
El. 46 ft.............	t_o	53.6	55.2	60.6	67.8	74.8	80.9	82.9	82.3	79.1	69.8	59.8	54.0
SOUTH DAKOTA													
Rapid City............	$\bar{I}_H$	687.8	1032.5	1503.7	1807	2028	2193.7	2235.8	2019.9	1628	1179.3	763.1	590.4
Lat. 44°09'N..........	K_t	0.601	0.627	0.649	0.594	0.574	0.583	0.612	0.622	0.628	0.624	0.566	0.588
El. 3218 ft...........	t_o	24.7	27.4	34.7	48.2	58.3	67.3	76.3	75.0	64.7	52.9	38.7	29.2
TEXAS													
Brownsville...........	$\bar{I}_H$	1105.9	1262.7	1505.9	1714	2092.2	2288.5	2345	2124	1774.9	1536.5	1104.8	982.3
Lat. 25°55'N..........	K_t	0.517	0.500	0.505	0.509	0.584	0.627	0.650	0.617	0.566	0.570	0.468	0.488
El. 20 ft.............	t_o	63.3	66.7	70.7	76.2	81.4	85.1	86.5	85.9	84.1	78.9	70.7	65.2
El Paso...............	$\bar{I}_H$	1247.6	1612.9	2048.7	2447.2	2673	2731	2391.1	2350.5	2077.5	1704.8	1324.7	1051.6
Lat. 31°48'N..........	K_t	0.686	0.714	0.730	0.741	0.743	0.733	0.652	0.669	0.693	0.695	0.647	0.626
El. 3916 ft...........	t_o	47.1	53.1	58.7	67.3	75.7	84.2	84.9	83.4	78.5	69.0	56.0	48.5
Fort Worth............	$\bar{I}_H$	936.2	1198.5	1597.8	1829.1	2105.1	2437.6	2293.3	2216.6	1880.8	1476	1147.6	913.6
Lat. 32°50'N..........	K_t	0.530	0.541	0.577	0.556	0.585	0.654	0.624	0.653	0.634	0.612	0.576	0.563
El. 544 ft............	t_o	48.1	52.3	59.8	68.8	75.9	84.0	87.7	88.6	81.3	71.5	58.8	50.8

Table A-4 (Continued)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TEXAS (Contd.)													
Midland...............	$\bar{I}_H$	1066.4	1345.7	1784.8	2036.1	2301.1	2317.7	2301.8	2193	1921.8	1470.8	1244.3	1023.2
Lat. 31°56'N..........	K_t	0.587	0.596	0.638	0.617	0.639	0.622	0.628	0.643	0.642	0.600	0.609	0.611
El. 2854 ft...........	t_o	47.9	52.8	60.0	68.8	77.2	83.9	85.7	85.0	78.9	70.3	56.6	49.1
San Antonio...........	$\bar{I}_H$	1045	1299.2	1560.1	1664.6	2024.7	2250*	2364.2	2185.2	1844.6	1487.4	1104.4	954.6
Lat. 29°32'N..........	K_t	0.541	0.550	0.542	0.500	0.563	0.62	0.647	0.637	0.603	0.584	0.507	0.528
El. 794 ft............	t_o	53.7	58.4	65.0	72.2	79.2	85.0	87.4	87.8	82.6	74.7	63.3	56.5
TENNESSEE													
Nashville.............	$\bar{I}_H$	589.7	907	1246.8	1662.3	1997	2149.4	2079.7	1862.7	1600.7	1223.6	823.2	614.4
Lat. 36°07'N..........	K_t	0.373	0.440	0.472	0.514	0.556	0.573	0.565	0.554	0.556	0.540	0.454	0.426
El. 605 ft............	t_o	42.6	45.1	52.9	63.0	71.4	80.1	83.2	81.9	76.6	65.4	52.3	44.3
Oak Ridge.............	$\bar{I}_H$	604	895.9	1241.7	1689.6	1942.8	2066.4	1972.3	1795.6	1559.8	1194.8	796.3	610
Lat. 36°01'N..........	K_t	0.382	0.435	0.471	0.524	0.541	0.551	0.536	0.534	0.542	0.527	0.438	0.422
El. 905 ft............	t_o	41.9	44.2	51.7	61.4	69.8	77.8	80.2	78.8	74.5	62.7	50.4	42.5
UTAH													
Salt Lake City........	$\bar{I}_H$	622.1	986	1301.1	1813.3	-	-	-	-	1689.3	1250.2	-	552.8
Lat. 40°46'N..........	K_t	0.468	0.909	0.529	0.579	-	-	-	-	0.621	0.610	-	0.467
El. 4227 ft...........	t_o	29.4	36.2	44.4	53.9	63.1	71.7	81.3	79.0	68.7	57.0	42.5	34.0
WASHINGTON													
Seattle...............	$\bar{I}_H$	282.6	520.6	992.2	1507	1881.5	1909.9	2110.7	1688.5	1211.8	702.2	386.3	239.5
Lat. 47°27'N..........	K_t	0.296	0.355	0.456	0.510	0.538	0.508	0.581	0.533	0.492	0.407	0.336	0.292
El. 386 ft............	t_o	42.1	45.0	48.9	54.1	59.8	64.4	68.4	67.9	63.3	56.3	48.4	44.4
Seattle...............	$\bar{I}_H$	252	471.6	917.3	1375.6	1664.9	1724	1805.1	1617	1129.1	638	325.5	218.1
Lat. 47°36'N..........	K_t	0.266	0.324	0.423	0.468	0.477	0.459	0.498	0.511	0.459	0.372	0.284	0.269
El. 14 ft.............	t_o	38.9	42.9	46.9	51.9	58.1	62.8	67.2	66.7	61.6	54.0	45.7	41.5
Spokane...............	$\bar{I}_H$	446.1	837.6	1200	1864.6	2104.4	2226.5	2479.7	2076	1511	844.6	486.3	279
Lat. 47°40'N..........	K_t	0.478	0.579	0.556	0.602	0.603	0.593	0.684	0.656	0.616	0.494	0.428	0.345
El.1968 ft............	t_o	26.5	31.7	40.5	49.2	57.9	64.6	73.4	71.7	62.7	51.5	37.4	30.5
WISCONSIN													
Madison...............	$\bar{I}_H$	564.6	812.2	1232.1	1455.3	1745.4	2031.7	2046.5	1740.2	1443.9	993	555.7	495.9
Lat. 43°08'N..........	K_t	0.40	0.478	0.522	0.474	0.493	0.540	0.559	0.534	0.549	0.510	0.396	0.467
El. 866 ft............	t_o	21.8	24.6	35.3	49.0	61.0	70.9	76.8	74.4	65.6	53.7	37.8	25.4
WYOMING													
Lander................	$\bar{I}_H$	786.3	1146.1	1638	1988.5	2114	2492.2	2438.4	2120.6	1712.9	1301.8	837.3	694.8
Lat. 42°48'N..........	K_t	0.65	0.672	0.691	0.647	0.597	0.662	0.665	0.649	0.647	0.666	0.589	0.643
El. 5370 ft...........	t_o	20.2	26.3	34.7	45.5	56.0	65.4	74.6	72.5	61.4	48.3	33.4	23.8

*Original values incorrect. Values estimated from insolation maps.

Storage Register Assignment

Average Daily Radiation Program

register number	
0	$\overline{H}_d/\overline{H}$
1	$\phi - s$
2	when azi = 0: $\omega'_s = \min[\omega_s, \arccos(-\tan(\phi - s) \times \tan\delta)]$ when azi ≠ 0: $A^2 + 1$
3	$\omega_s = \arccos(-\tan\phi \times \tan\delta)$
4	$\sin\delta$
5	$\cos\delta$
6	37242737: alpha. for TILT
7	13462430: alpha. for AZIM
8	35172127: alpha. for REFL.
9	13421700: alpha. for AVE
10	$A = \cos\phi/[\sin\gamma \tan s] + \sin\phi/\tan\gamma$
11	$B = \tan\delta[\cos\phi/\tan\gamma - \sin\phi/[\sin\gamma \tan s]]$
12	min. $(\omega_s, \arccos[(AB - \sqrt{A^2-B^2+1})/A^2 + 1])$
13	min. $(\omega_s, \arccos[(AB + \sqrt{A^2-B^2+1}/A^2 + 1])$
14	16242121: alpha. for BEAM
15	$\sqrt{A^2-B^2+1}$
16	$\overline{R}_b$
17	61174437: alpha. for %EXT
18	27133700: alpha. for LAT
19	16171527: alpha. for DECL
20	Total radiation
21	$\overline{H}$ = monthly average daily total radiation on horizontal surface
22	$\overline{K}_T$ = the fraction of extraterrestrial radiation transmitted through the atmosphere
23	ϕ = latitude (degrees)
24	ρ = ground reflection
25	s = tilt of surface from horizontal (degrees)
26	γ = surface azimuth angle (east-,west+) (degrees)
27	δ = declination (degrees)
28	ω_{ss}
29	ω_{sr}

AVERAGE DAILY RADIATION: PRINTER VERSION*
LISTING: CARD SIDES 1, 2, & 3

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000  76  LBL
001  11   A
002  42  STO
003  25   25
004  43  RCL
005  06   06
006  69  OP
007  04   04
008  43  RCL
009  25   25
010  69  OP
011  06   06
012  91  R/S
013  76  LBL
014  12   B
015  42  STO
016  26   26
017  43  RCL
018  07   07
019  69  OP
020  04   04
021  43  RCL
022  26   26
023  69  OP
024  06   06
025  91  R/S
026  76  LBL
027  13   C
028  42  STO
029  24   24
030  43  RCL
031  08   08
032  69  OP
033  04   04
034  43  RCL
035  24   24
036  69  OP
037  06   06
038  91  R/S
039  76  LBL
040  14   D
041  42  STO
042  21   21
043  25  CLR
044  43  RCL
045  09   09
046  69  OP
047  04   04
048  43  RCL
049  21   21
050  69  OP
051  06   06
052  91  R/S
053  76  LBL
054  15   E
055  42  STO
056  22   22
057  43  RCL
058  17   17
059  69  OP
060  04   04
061  43  RCL
062  22   22
063  69  OP
064  06   06
065  91  R/S
066  76  LBL
067  16  A'
068  42  STO
069  23   23
070  43  RCL
071  18   18
072  69  OP
073  04   04
074  43  RCL
075  23   23
076  69  OP
077  06   06
078  91  R/S
079  76  LBL
080  17  B'
081  42  STO
082  27   27
083  43  RCL
084  19   19
085  69  OP
086  04   04
087  43  RCL
088  27   27
089  69  OP
090  06   06
091  91  R/S
092  76  LBL
093  18  C'
094  98  ADV
095  53   (
096  43  RCL
097  23   23
098  30  TAN
099  94  +/-
100  65   ×
101  43  RCL
102  27   27
103  30  TAN
104  54   )
105  22  INV
106  39  COS
107  95   =
108  42  STO
109  03   03
110  42  STO
111  02   02
112  42  STO
113  12   12
114  42  STO
115  13   13
116  43  RCL
117  27   27
118  38  SIN
119  95   =
120  42  STO
121  04   04
122  43  RCL
123  27   27
124  39  COS
125  95   =
126  42  STO
127  05   05
128  00   0
129  32  X:T
130  43  RCL
131  26   26
132  22  INV
133  67   EQ
134  50  I×I
135  43  RCL
136  23   23
137  75   -
138  43  RCL
139  25   25
140  95   =
141  42  STO
142  01   01
143  43  RCL
144  03   03
145  32  X:T
146  53   (
147  43  RCL
148  01   01
149  30  TAN
150  94  +/-
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*TO CHANGE PROGRAM INTO NON-PRINTER VERSION SIMPLY REPLACE THE PAUSE INSTRUCTIONS AT LOCATIONS 302, 331, 366 & 387 WITH R/S INSTRUCTIONS

151	65	×
152	43	RCL
153	27	27
154	30	TAN
155	54	)
156	22	INV
157	39	COS
158	95	=
159	22	INV
160	77	GE
161	80	GRD
162	61	GTO
163	60	DEG
164	76	LBL
165	80	GRD
166	42	STO
167	02	02
168	61	GTO
169	60	DEG
170	91	R/S
171	76	LBL
172	60	DEG
173	53	(
174	43	RCL
175	01	01
176	39	COS
177	65	×
178	43	RCL
179	05	05
180	65	×
181	43	RCL
182	02	02
183	38	SIN
184	85	+
185	89	π
186	55	÷
187	01	1
188	08	8
189	00	0
190	65	×
191	43	RCL
192	02	02
193	65	×
194	43	RCL
195	01	01
196	38	SIN
197	65	×
198	43	RCL
199	04	04
200	54	)
201	55	÷
202	53	(
203	43	RCL
204	23	23
205	39	COS
206	65	×
207	43	RCL
208	05	05
209	65	×
210	43	RCL
211	03	03
212	38	SIN
213	85	+
214	89	π
215	55	÷
216	01	1
217	08	8
218	00	0
219	65	×
220	43	RCL
221	03	03
222	65	×
223	43	RCL
224	23	23
225	38	SIN
226	65	×
227	43	RCL
228	04	04
229	95	=
230	42	STO
231	16	16
232	76	LBL
233	23	LNX
234	00	0
235	32	X:T
236	01	1
237	93	.
238	03	3
239	09	9
240	75	-
241	04	4
242	93	.
243	00	0
244	03	3
245	65	×
246	43	RCL
247	22	22
248	85	+
249	05	5
250	93	.
251	05	5
252	03	3
253	65	×
254	43	RCL
255	22	22
256	33	X^2
257	75	-
258	03	3
259	93	.
260	01	1
261	01	1
262	65	×
263	43	RCL
264	22	22
265	45	Y^X
266	03	3
267	95	=
268	42	STO
269	00	00
270	01	1
271	04	4
272	01	1
273	07	7
274	01	1
275	03	3
276	03	3
277	00	0
278	69	OP
279	04	04
280	53	(
281	53	(
282	01	1
283	75	-
284	43	RCL
285	00	00
286	54	)
287	65	×
288	43	RCL
289	16	16
290	54	)
291	65	×
292	43	RCL
293	21	21
294	95	=
295	58	FIX
296	01	01
297	22	INV
298	77	GE
299	45	Y^X
300	76	LBL

301	78	Σ+
*302	66	PAU
303	69	OP
304	06	06
305	22	INV
306	58	FIX
307	42	STO
308	20	20
309	43	RCL
310	14	14
311	69	OP
312	04	04
313	43	RCL
314	00	00
315	65	×
316	53	(
317	01	1
318	85	+
319	43	RCL
320	25	25
321	39	COS
322	54	)
323	55	÷
324	02	2
325	65	×
326	43	RCL
327	21	21
328	95	=
329	58	FIX
330	01	01
*331	66	PAU
332	69	OP
333	06	06
334	22	INV
335	58	FIX
336	44	SUM
337	20	20
338	03	3
339	05	5
340	01	1
341	07	7
342	02	2
343	01	1
344	02	2
345	07	7
346	69	OP
347	04	04
348	43	RCL
349	24	24
350	65	×
351	53	(
352	01	1
353	75	-
354	43	RCL
355	25	25
356	39	COS
357	54	)
358	55	÷
359	02	2
360	65	×
361	43	RCL
362	21	21
363	95	=
364	58	FIX
365	01	01
*366	66	PAU
367	69	OP
368	06	06
369	22	INV
370	58	FIX
371	44	SUM
372	20	20
373	03	3
374	07	7
375	03	3
376	02	2
377	03	3
378	07	7
379	02	2
380	07	7
381	69	OP
382	04	04
383	43	RCL
384	20	20
385	58	FIX
386	01	01
*387	66	PAU
388	69	OP
389	06	06
390	98	ADV
391	98	ADV
392	98	ADV
393	22	INV
394	58	FIX
395	91	R/S
396	76	LBL
397	45	Y^X
398	00	0
399	61	GTO
400	78	Σ+
401	76	LBL
402	50	I×I
403	43	RCL
404	03	03
405	32	X:T
406	53	(
407	43	RCL
408	23	23
409	39	COS
410	55	÷
411	53	(
412	43	RCL
413	26	26
414	38	SIN
415	65	×
416	43	RCL
417	25	25
418	30	TAN
419	54	)
420	85	+
421	43	RCL
422	23	23
423	38	SIN
424	55	÷
425	43	RCL
426	26	26
427	30	TAN
428	54	)
429	42	STO
430	10	10
431	53	(
432	43	RCL
433	27	27
434	30	TAN
435	65	×
436	53	(
437	43	RCL
438	23	23
439	39	COS
440	55	÷
441	43	RCL
442	26	26
443	30	TAN
444	75	-
445	43	RCL
446	23	23
447	38	SIN
448	55	÷
449	53	(
450	43	RCL

* R/S, <u>NOT</u> PAUSE FOR NON-PRINTER VERSION

451	26	2ND
452	38	SIN
453	65	×
454	43	RCL
455	25	25
456	30	TAN
457	95	=
458	42	STO
459	11	11
460	33	X²
461	94	+/-
462	85	+
463	43	RCL
464	10	10
465	33	X²
466	85	+
467	01	1
468	95	=
469	34	√X
470	42	STO
471	15	15
472	53	(
473	43	RCL
474	10	10
475	65	×
476	43	RCL
477	11	11
478	85	+
479	43	RCL
480	15	15
481	54	)
482	55	÷
483	53	(
484	43	RCL
485	10	10
486	33	X²
487	85	+
488	01	1
489	54	)
490	42	STO
491	02	02
492	95	=
493	22	INV
494	39	COS
495	77	GE
496	70	RAD
497	42	STO
498	13	13
499	76	LBL
500	70	RAD
501	53	(
502	43	RCL
503	10	10
504	65	×
505	43	RCL
506	11	11
507	75	-
508	43	RCL
509	15	15
510	54	)
511	55	÷
512	43	RCL
513	02	02
514	95	=
515	22	INV
516	39	COS
517	77	GE
518	30	TAN
519	42	STO
520	12	12
521	76	LBL
522	30	TAN
523	00	0
524	32	X⇄T
525	43	RCL
526	26	26
527	77	GE
528	28	LOG
529	43	RCL
530	12	12
531	94	+/-
532	42	STO
533	29	29
534	43	RCL
535	13	13
536	42	STO
537	28	28
538	61	GTO
539	48	EXC
540	76	LBL
541	28	LOG
542	43	RCL
543	13	13
544	94	+/-
545	42	STO
546	29	29
547	43	RCL
548	12	12
549	42	STO
550	28	28
551	76	LBL
552	48	EXC
553	53	(
554	43	RCL
555	25	25
556	39	COS
557	65	×
558	43	RCL
559	04	04
560	65	×
561	43	RCL
562	23	23
563	38	SIN
564	54	)
565	65	×
566	89	π
567	55	÷
568	01	1
569	08	8
570	00	0
571	65	×
572	53	(
573	43	RCL
574	28	28
575	75	-
576	43	RCL
577	29	29
578	54	)
579	75	-
580	53	(
581	43	RCL
582	04	04
583	65	×
584	43	RCL
585	23	23
586	39	COS
587	65	×
588	43	RCL
589	25	25
590	38	SIN
591	65	×
592	43	RCL
593	26	26
594	39	COS
595	54	)
596	65	×
597	89	π
598	55	÷
599	01	1
600	08	8

601	00	0
602	65	×
603	53	(
604	43	RCL
605	28	28
606	75	-
607	43	RCL
608	29	29
609	54	)
610	85	+
611	53	(
612	43	RCL
613	23	23
614	39	COS
615	65	×
616	43	RCL
617	05	05
618	65	×
619	43	RCL
620	25	25
621	39	COS
622	54	)
623	65	×
624	53	(
625	43	RCL
626	28	28
627	38	SIN
628	75	-
629	43	RCL
630	29	29
631	38	SIN
632	54	)
633	85	+
634	53	(
635	43	RCL
636	05	05
637	65	×
638	43	RCL
639	26	26
640	39	COS
641	65	×
642	43	RCL
643	23	23
644	38	SIN
645	65	×
646	43	RCL
647	25	25
648	38	SIN
649	54	)
650	65	×
651	53	(
652	43	RCL
653	28	28
654	38	SIN
655	75	-
656	43	RCL
657	29	29
658	38	SIN
659	54	)
660	75	-
661	53	(
662	43	RCL
663	05	05
664	65	×
665	43	RCL
666	25	25
667	38	SIN
668	65	×
669	43	RCL
670	26	26
671	38	SIN
672	54	)
673	65	×
674	53	(
675	43	RCL
676	28	28
677	39	COS
678	75	-
679	43	RCL
680	29	29
681	39	COS
682	95	=
683	55	÷
684	53	(
685	02	2
686	65	×
687	53	(
688	43	RCL
689	23	23
690	39	COS
691	65	×
692	43	RCL
693	05	05
694	65	×
695	43	RCL
696	03	03
697	38	SIN
698	85	+
699	89	π
700	55	÷
701	01	1
702	08	8
703	00	0
704	65	×
705	43	RCL
706	03	03
707	65	×
708	43	RCL
709	23	23
710	38	SIN
711	65	×
712	43	RCL
713	04	04
714	95	=
715	42	STO
716	16	16
717	25	CLR
718	61	GTO
719	23	LNX

CARD SIDE 4: DATA

0.	00
0.	01
0.	02
0.	03
0.	04
0.	05
37242737.	06
13462430.	07
35172127.	08
13421700.	09
0.	10
0.	11
0.	12
0.	13
16242121.	14
0.	15
0.	16
61174437.	17
27133700.	18
16171527.	19
0.	20
0.	21
0.	22
0.	23
0.	24
0.	25
0.	26
0.	27
0.	28
0.	29

LABELS

001	11	A
014	12	B
027	13	C
040	14	D
054	15	E
067	16	A'
080	17	B'
093	18	C'
165	80	GRD
172	60	DEG
233	23	LNX
301	78	Σ+
397	45	Y^X
402	50	I×I
500	70	RAD
522	30	TAN
541	28	LOG
552	48	EXC

Solar Energy, Vol. 19, pp. 325-329. Pergamon Press 1977. Printed in Great Britain

REVIEW PAPER

CALCULATION OF MONTHLY AVERAGE INSOLATION ON TILTED SURFACES

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(*Received* 16 *June* 1976; *in revised form* 28 *October* 1976)

Abstract—Several simplified design procedures for solar energy systems require monthly average meteorological data. Monthly average daily totals of the solar radiation incident on a horizontal surface are available. However, radiation data on tilted surfaces, required by the design procedures, are generally not available. A simple method of estimating the average daily radiation for each calendar month on surfaces facing directly towards the equator has been presented by Liu and Jordan[1]. This method is verified with experimental measurements and extended to allow calculation of monthly average radiation on surfaces of a wide range of orientations.

INTRODUCTION

Estimates of the monthly average solar radiation incident on surfaces of various orientations are required for solar energy design procedures, heating load calculations, and other applications. Monthly averages of the daily solar radiation incident upon a horizontal surface are available for many locations. However, radiation data on tilted surfaces are generally not available.

A simple method of estimating the average daily radiation for each calendar month on surfaces facing directly towards the equator has been developed by Liu and Jordan[1]. Their method is described here and compared with the work of Page[2] and with additional experimental measurements. The method is then extended so that it is applicable for surfaces oriented east or west of south.

ESTIMATION OF AVERAGE DAILY RADIATION ON SURFACES FACING DIRECTLY TOWARDS THE EQUATOR

The average daily radiation on a horizontal surface, $\bar{H}$, for each calendar month can be expressed by defining $\bar{K}_T$, the fraction of the mean daily extraterrestrial radiation, $\bar{H}_0$.

$$\bar{K}_T = \bar{H}/\bar{H}_0 \tag{1}$$

$$\bar{H}_0 = \frac{1}{(m_2 - m_1)} \sum_{n=m_1}^{m_2} (H_0)_n \tag{2}$$

where m_1 and m_2 are, respectively, the days of the year at the start and end of the month and $(H_0)_n$ is the extraterrestrial radiation on a horizontal surface on day n of the year which is given by

$$(H_0)_n = \frac{24}{\pi} I_{sc} \left[1 + 0.033 \cos\left(\frac{360n}{365}\right)\right] \times [\cos\phi \cos\delta \sin\omega_s + (\omega_s 2\pi/360) \sin\phi \sin\delta] \tag{3}$$

where I_{sc} is the solar constant, n is the day of the year given for each month in Table 1, ϕ is the latitude, and δ is the solar declination which can be approximately expressed

$$\delta = 23.45° \sin[360(284 + n)/365] \tag{4}$$

ω_s is the sunset hour angle

$$\cos\omega_s = -\tan\phi \tan\delta. \tag{5}$$

$\bar{H}_0$ can be conveniently estimated from eqn (3) by selecting for each month, the day of the year for which the daily extraterrestrial radiation is nearly the same as the monthly mean value. Using the 16th day of each month can lead to small errors in $\bar{H}_0$, particularly for June and December. Recommended days for each month are given in Table 1. $\bar{H}_0$ is tabulated for each month as a function of latitude in Table 2. The value of the solar constant used in the construction of Table 2 is 4871 kJ hr^{-1} m^{-2}, Thekaekara and Drummond[3]], which is approximately 3 per cent lower than the value used by Liu and Jordan[1, 4] and Page[2].

The average daily radiation on a tilted surface, $\bar{H}_T$, can

Table 1. Recommended average day for each month

Month	Day of the year	Date
Jan.	17	17 Jan.
Feb.	47	16 Feb.
Mar.	75	16 Mar.
Apr.	105	15 Apr.
May	135	15 May
June	162	11 June
July	198	17 July
Aug.	228	16 Aug.
Sept.	258	15 Sept.
Oct.	288	15 Oct.
Nov.	318	14 Nov.
Dec.	344	10 Dec.

Table 2. Monthly average daily extraterrestrial radiation, kJ/m²

Lat.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
25	23,902	28.115	32.848	37,111	39,356	40.046	39.606	37.832	34.238	29.413	24,909	22,669
30	21.034	25.679	31,141	36,436	39,569	40,706	40.071	37,534	32,917	27.213	22,161	19,714
35	18,069	23,072	29,200	35,497	39,530	41.129	40.292	36,976	31.348	24.820	19.296	16,687
40	15,403	20,319	27,040	34,303	39,247	41,328	40.281	36,166	29,542	22.255	16,344	13,626
45	11.998	17,448	24,677	32.869	38,737	41,322	40.055	35,118	27.515	19.541	13,344	10,579
50	8987	14.490	22.131	31,209	38,025	41,147	39.644	33,851	25.283	16.705	10.342	7605
55	6082	11.486	19,423	29,345	37,152	40,863	39,100	32,391	22.863	13,778	7396	4791

be expressed

$$\bar{H}_T = \bar{R}\bar{H} = \bar{R}\bar{K}_T\bar{H}_0 \tag{6}$$

where $\bar{R}$ is defined to be the ratio of the daily average radiation on a tilted surface to that on a horizontal surface for each month. $\bar{R}$ can be estimated by individually considering the beam, diffuse, and reflected components of the radiation incidence on the tilted surface. Assuming diffuse and reflected radiation to be isotropic, Liu and Jordan[1] have proposed that $\bar{R}$ can be expressed

$$\bar{R} = (1 - \bar{H}_d/\bar{H})\bar{R}_b + \bar{H}_d/\bar{H}(1 + \cos s)/2 + \rho(1 - \cos s)/2 \tag{7}$$

where $\bar{H}_d$ is the monthly average daily diffuse radiation, $\bar{R}_b$ is the ratio of the average beam radiation on the tilted surface to that on a horizontal surface for each month, s is the tilt of the surface from horizontal, and ρ is the ground reflectance. Liu and Jordan[4] suggest that ρ varies from 0.2 to 0.7 depending upon the extent of snow cover. $\bar{R}_b$ is a function of the transmittance of the atmosphere (except during times of equinox) which depends upon the atmospheric cloudiness, water vapor and particulate concentration. However, Liu and Jordan suggest that $\bar{R}_b$ can be estimated to be the ratio of extraterrestrial radiation on the tilted surface to that on a horizontal surface for the month. For surfaces facing directly towards the equator,

$$\bar{R}_b = \frac{\cos(\phi - s)\cos\delta\sin\omega_s' + \pi/180\omega_s'\sin(\phi - s)\sin\delta}{\cos\phi\cos\delta\sin\omega_s + \pi/180\omega_s\sin\phi\sin\delta} \tag{8}$$

where ω is the hour angle which is 15° × (hours from solar noon), afternoons, positive, mornings negative and ω_s' is the sunset hour angle for the tilted surface which is given by

$$\omega_s' = \min[\omega_s, \arccos[-\tan(\phi - s)\tan\delta]]. \tag{9}$$

Page has calculated values of $\bar{R}_b$ for five surface orientations of several latitudes by integrating the direct radiation on the tilted and horizontal surface calculated at hourly intervals for a standard direct radiation curve. Values of $\bar{R}_b$ calculated from eqn (8) are in reasonably good agreement with the values tabulated by Page as seen in Table 3. Page's values are slightly more conservative, i.e. closer to unity.

Since measurements of $\bar{H}_d$, the monthly average daily diffuse radiation are rarely available, $\bar{H}_d$ must be estimated from measurements of the average daily total radiation. A number of investigators have found that the diffuse radiation fraction, $\bar{H}_d/\bar{H}$, is a function of $\bar{K}_T$. Shown in Fig. 1 are the relationships reported by Liu and Jordan, and Page which can be expressed

K_T

$$\frac{\bar{H}_d}{\bar{H}} = \begin{cases} 1.390 - 4.027\bar{K}_T + 5.531\bar{K}_T^2 - 3.108\bar{K}_T^3 & \text{[Liu \& Jordan]} \quad (10a) \\ 1.00 - 1.13\bar{K}_T & \text{[Page].} \quad (10b) \end{cases}$$

Table 3. Comparison of values of $\bar{R}_b$ from Page[2] and eqn (8)

	$\phi = 30°$				$\phi = 40°$			
	$\phi - s = 0$		Vertical		$\phi - s = 0$		Vertical	
	Page	Eqn (8)	Page	Eqn (8)	Page	Eqn (8)	Page	Eqn (8)
Jan.	1.61	1.66	1.49	1.59	2.15	2.26	2.11	2.32
Feb.	1.40	1.43	1.06	1.13	1.72	1.79	1.50	1.59
Mar.	1.18	1.20	0.64	0.67	1.35	1.38	0.93	0.96
Apr.	0.99	1.00	0.29	0.30	1.07	1.06	0.48	0.48
May	0.89	0.87	0.13	0.11	0.90	0.88	0.27	0.25
June	0.84	0.87	0.06	0.05	0.84	0.80	0.19	0.17
July	0.85	0.84	0.09	0.08	0.85	0.83	0.22	0.21
Aug.	0.94	0.94	0.21	0.21	0.98	0.98	0.37	0.37
Sept.	1.09	1.12	0.45	0.50	1.20	1.24	0.69	0.74
Oct.	1.30	1.35	0.88	0.97	1.57	1.64	1.24	1.36
Nov.	1.53	1.60	1.33	1.46	1.98	2.12	1.86	2.10
Dec.	1.67	1.74	1.61	1.74	2.30	2.42	2.36	2.58

Page's relationship, which was derived from experimental measurements at 10 stations, tends to agree more closely with the additional measurements reported by Choudhury[5], Stanhill[6] and Norris[7]. The discrepancy is apparently due, at least in part, to the fact that a shade ring correction factor was applied to all reported diffuse radiation measurements except those taken at Blue Hill, Massachusetts, which Liu and Jordan used to derive their relationship. Page's relationship probably results in a more accurate estimate of the diffuse radiation fraction; however, values of $\bar{R}$ estimated from eqn (7) with $\rho = 0.2$ tend to agree more closely with experimental measurements when the Liu and Jordan relationship is used, as shown in the next section.

COMPARISON WITH EXPERIMENTAL RESULTS

Long-term measurements of the radiation incident on both tilted and horizontal surfaces are scarce. Measurements of the radiation incident on a horizontal and a south-facing vertical surface in Blue Hill, Massachusetts (lat. 42.2°N) for the yr 1952–56 have been presented by Liu and Jordan. In Table 4 experimental values of $\bar{R}$ are compared with values estimated from eqn (7) with $\rho = 0.2$ using the diffuse radiation fraction relationships of Liu and Jordan (eqn 10a) and Page (eqn 10b). In Table 5, similarly calculated values of $\bar{R}$ are compared with experimental values for a 38° north-facing surface at Highett, Victoria, Australia (lat. 37.9°S) for the years 1966–68[8]. Based on this experimental data, it appears that Liu and Jordan's relationship for the diffuse radiation fraction (eqn 10a) results in more accurate values of $\bar{R}$ than does Page's (eqn 10b). It is possible that the "underestimated" diffuse radiation fraction arising from eqn (10a) tends to cancel errors caused by the conservative assumptions of isotropic diffuse radiation and a ground reflectance of 0.2.

ESTIMATION OF AVERAGE DAILY RADIATION ON SURFACES ORIENTED EAST OR WEST OF SOUTH

Liu and Jordan's method of calculating $\bar{R}_b$ can be extended so that it is applicable for surfaces which are not oriented directly towards the equator by integrating the rate of extraterrestrial radiation on the surface for the period during which the sun is both above the horizon and in front of the surface and then dividing this

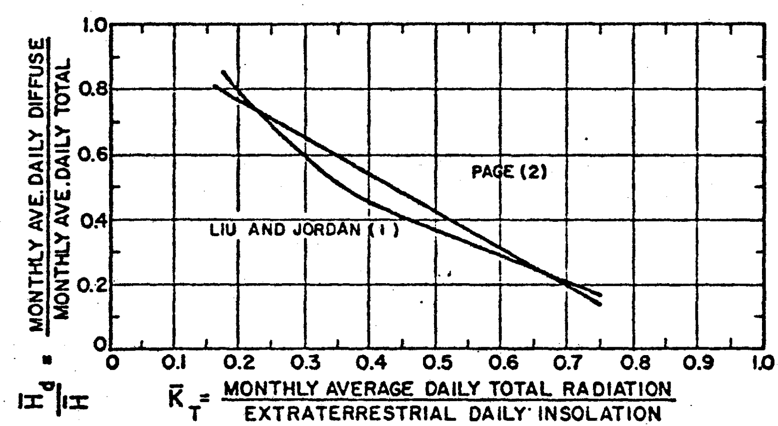


Fig. 1. Relationship of $\bar{H}_d/\bar{H}$ to $\bar{K}_T$.

Table 4. Comparison of experimental† and estimated values of $\bar{R}$ for a vertical surface facing south at Blue Hill, Mass., lat. 42°13′N

Month	K_T	$\bar{R}$ Experimental† (1952–56)	$\bar{R}$ Estimated from eqns (7) and (10a)	$\bar{R}$ Estimated from eqns (7) and (10b)
Jan.	0.411	1.80	1.72	1.55
Feb.	0.445	1.38	1.31	1.22
Mar.	0.445	0.93	0.91	0.87
Apr.	0.440	0.61	0.62	0.62
May	0.481	0.44	0.47	0.48
June	0.524	0.39	0.41	0.42
July	0.528	0.42	0.42	0.44
Aug.	0.485	0.54	0.55	0.55
Sept.	0.485	0.79	0.79	0.77
Oct.	0.466	1.23	1.18	1.11
Nov.	0.421	1.60	1.61	1.46
Dec.	0.422	1.94	1.91	1.72

†Source: Liu and Jordan (1962)[1].

Table 5. Comparison of experimental and estimated values of $\bar{R}$ for a 38° surface facing north at Melbourne, Australia, lat. 37.9°S

Month	K_T	$\bar{R}$ Experimental† (1966–68)	$\bar{R}$ Estimated from eqns (7) and (10a)	$\bar{R}$ Estimated from eqns (7) and (10b)
Jan.	0.46	0.85	0.88	0.89
Feb.	0.46	0.94	0.96	0.96
Mar.	0.41	1.10	1.09	1.06
Apr.	0.40	1.29	1.27	1.21
May	0.34	1.37	1.41	1.33
June	0.34	1.50	1.54	1.44
July	0.37	1.50	1.55	1.42
Aug.	0.39	1.34	1.34	1.28
Sept.	0.38	1.15	1.14	1.10
Oct.	0.39	0.98	0.99	0.98
Nov.	0.41	0.88	0.90	0.90
Dec.	0.42	0.84	0.86	0.87

result by $\bar{H}_0$. In this case

$$\bar{R}_b = \{[\cos s \sin \delta \sin \phi]\pi/180[\omega_{ss} - \omega_{sr}] - [\sin \delta \cos \phi \sin s \cos \gamma]\pi/180[\omega_{ss} - \omega_{sr}] + [\cos \phi \cos \delta \cos s][\sin \omega_{ss} - \sin \omega_{sr}] + [\cos \delta \cos \gamma \sin \phi \sin s][\sin \omega_{ss} - \sin \omega_{sr}] - [\cos \delta \sin s \sin \gamma][\cos \omega_{ss} - \cos \omega_{sr}]\}/ \{2[\cos \phi \cos \delta \sin \omega_s + \pi/180\omega_s \sin \phi \sin \delta]\} \quad (11)$$

where γ is the surface azimuth angle, i.e. the deviation of the normal to the surface from the local meridan, the zero point being due south, east negative, and west positive. ω_{sr} and ω_{ss} are the sunrise and sunset hour angles on the tilted surface, given by

if $\gamma > 0$

$$\omega_{sr} = -\min[\omega_s, \arccos[(AB + \sqrt{A^2 - B^2 + 1})/(A^2 + 1)]] \quad (12)$$
$$\omega_{ss} = \min[\omega_s, \arccos[(AB - \sqrt{A^2 - B^2 + 1})/(A^2 + 1)]]$$

if $\gamma < 0$

$$\omega_{sr} = -\min[\omega_s, \arccos[(AB - \sqrt{A^2 - B^2 + 1})/(A^2 + 1)]]$$
if $\gamma > 0$ (13)
$$\omega_{ss} = \min[\omega_s, \arccos[(AB + \sqrt{A^2 - B^2 + 1})/(A^2 + 1)]]$$

$$A = \cos \phi/[\sin \gamma \tan s] + \sin \phi/\tan \gamma \quad (14)$$
$$B = \tan \delta[\cos \phi/\tan \gamma - \sin \phi/[\sin \gamma \tan s]]. \quad (15)$$

An example demonstrating this method of estimating radiation on tilted surfaces follows.

EXAMPLE

Estimate the monthly averages of daily radiation incident on a surface tilted 43° from horizontal facing due south in Madison, Wisconsin (43°N lat.) and compare them with those incident if the surface were oriented 15° west of south.

Daily averages value of $\bar{H}$, the radiation incident on a horizontal surface can be found in Ref. [9]. The mean daily extraterrestrial radiation, $\bar{H}_0$, for each month can be determined from eqn (3) (using the days of the year in Table 1) or from Table 2 with interpolation. The ratio $\bar{H}/\bar{H}_O$ determines $\bar{K}_T$ for each month which can be used to calculate $\bar{H}_d/\bar{H}$ from eqn (10a) or (10b); (eqn (10a) is used in this example.) $\bar{R}$ is calculated from values of $\bar{R}_b$ for each month for both the south (eqn 8) and the 15° west of south (eqn 11) surfaces. The average daily radiation on each of the surfaces is the product of $\bar{R}\bar{H}$ for each month. These results are displayed in Table 6.

REFERENCES

1. B. Y. H. Liu and R. C. Jordan, Daily insolation on surfaces tilted toward the equator. *Trans. ASHRAE* 526–541 (1962).

Table 6. Calculation of daily average radiation on a 43° surface in Madison

Month	$\bar{H}$ Kj m² day⁻¹	$\bar{H}_0$ KJ m² day⁻¹	$\bar{K}_T$	$\bar{H}_d/\bar{H}$	$\bar{R}_b$ $\gamma = 0°$	$\bar{R}_b$ $\gamma = 15°$	$\bar{R}$ $\gamma = 0°$	$\bar{R}$ $\gamma = 15°$	$\bar{H}_T$ $\gamma = 0$ KJ m² day⁻¹	$\bar{H}_T$ $\gamma = 15°$ KJ m² day⁻¹
Jan.	6412	13,226	0.485	0.384	2.53	2.47	1.92	1.88	12,300	12,100
Feb.	9224	18,612	0.496	0.374	1.95	1.90	1.57	1.54	14,500	14,200
Mar.	13,992	25,762	0.543	0.337	1.46	1.44	1.28	1.27	18,000	17,800
Apr.	16,527	33,429	0.494	0.376	1.09	1.09	1.03	1.03	17,100	17,100
May	19,821	39,011	0.508	0.365	0.88	0.89	0.90	0.91	17,900	18,000
June	23,073	41,348	0.558	0.325	0.80	0.81	0.85	0.86	19,600	19,700
July	23,241	40,136	0.579	0.310	0.84	0.85	0.87	0.88	20,300	20,400
Aug.	19,762	35,552	0.556	0.327	0.99	1.00	0.98	0.98	19,400	19,400
Sept.	16,397	28,499	0.575	0.313	1.30	1.30	1.19	1.18	19,500	19,400
Oct.	11,277	20,684	0.545	0.335	1.77	1.73	1.49	1.47	16,800	16,500
Nov.	6311	14,472	0.436	0.428	2.36	2.30	1.75	1.71	11,000	10,800
Dec.	5632	11,785	0.478	0.390	2.75	2.68	2.04	2.00	11,500	11,300

2. J. K. Page, The estimation of monthly mean values of daily total short-wave radiation on vertical and inclined surfaces from sunshine records for latitudes 40°N–40°S. *Proc. UN Conf. on New Sources of Energy*, Paper No. 35/5/98 (1961).
3. M. P. Thekaekara and A. J. Drummond, Standard values for the solar constant and its spectral components. *Nat. Phys. Sci.* **229**(6) (1971).
4. B. Y. H. Liu and R. C. Jordan, The interrelationship and characteristic distribution of direct, diffuse, and total solar radiation. *Solar Energy* **4**(3) (1960).
5. N. K. O. Choudhury, Solar radiation at New Delhi. *Solar Energy* 7(2), 44–52 (1963).
6. G. Stanhill, Diffuse sky and cloud radiation in Israel. *Solar Energy* **10**(2), 96–101 (1966).
7. D. J. Norris, Solar radiation on inclined surfaces. *Solar Energy* **10**, 72–77 (1966).
8. J. W. Bannister, *Solar Radiation Records*. Division of Mech. Engng, Commonwealth Scientific and Industrial Research Organization, Highett, Victoria, Australia (1966–1969).
9. B. Y. H. Liu and R. C. Jordan, The long-term average performance of flat-plate solar energy collectors. *Solar Energy* **7**, 53–74 (1963).

Solar Angles & Radiation Program

TITLE DAILY PROFILE SOLAR ANGLES & RADIATION © PAGE 1 OF 10

TI Programmable Program Record

PROGRAMMER Cris Benton DATE 1 May 1978

Partitioning (Op 17) Std. Library Module ----- Printer yes Cards 5

PROGRAM DESCRIPTION

Given base data, calculates solar altitude, solar azimuth, angle of incidence to a specified plane, hourly quantities of direct, diffuse and total radiation at same plane, and radiation transmitted through specified glazing in same plane. Tabular output is optional, graphic output summarizes daily patterns of each variable. Daily total incident and transmitted radiation values are listed. Program prompts input of transmission values and card reading. Calculations are via ASHRAE procedures.

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
1	Read card sides 1 & 2	0				1,2
2*	Enter latitude	latitude	sto	0	2	latitude
3*	Enter longitude	longitude	sto	0	3	longitude
4*	Enter atmospheric clearance factor	acf	sto	0	4	acf
5*	Enter eq. of time (0 for solar noon)		sto	0	5	eq. time
6*	Enter declination	declin.	sto	0	6	declin.
7*	Enter A in BTUH/SF	A	sto	0	7	A
8*	Enter B (air mass correction)	B	sto	0	8	B
9*	Enter C (dimensionless)	C	sto	0	9	C
10	Enter ground reflectance as factor	ground	sto	1	0	.ground
11	Enter wall tilt (vert. = 90)	tilt	sto	1	1	tilt
12	Enter wall orientation (+east, -west)		sto	1	2	orient.
13	List input data for ref.	0	inv	2nd	list	r/s @ 12
14	Record data for re-use (optional)	4	2nd	write		4
15	Reset	0	rst			0
16	For no tabular output	0	2nd	stflg	1	0
17	Run	0	R/S			
18	Reset	0	rst			
19	Read card sides 3,4,&5 on prompt	0				1,2,4
20	Run	0	R/S			
21*	Enter transmission values on prompt	value	R/S			prompt
22	Run	0	R/S			graphs

* Note, values for this input may be found in the appendix. Program listings, alpha register listing, sample output & appendix follow.

USER DEFINED KEYS	
A	used for sub-routines
B	
C	
D	
E	
A'	
B'	
C'	
D'	
E'	

DATA REGISTERS (INV LIST)			
0		20	normal energy
1		21	dir. E @ plane
2		22	Fsg ground
13	long corr.	23	Fss sky
14	hour in min.	24	sky diffuse
15	hour angle	25	grd. diffuse
16	altitude	26	total diffuse
17	azimuth	27	total E
18	wall sun angle	28	sum E
19	angle incid.	29	counter

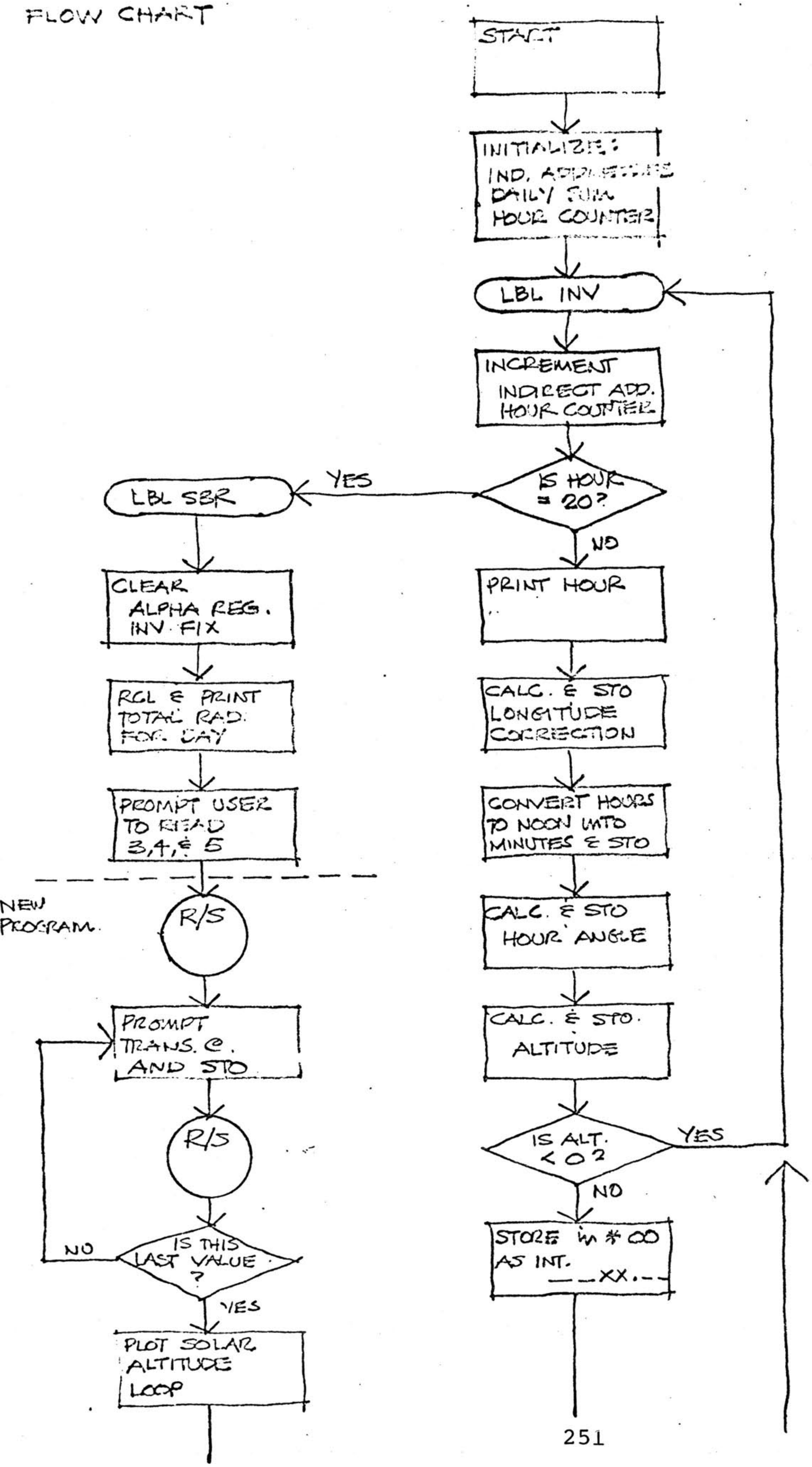
LABELS (Op 08)

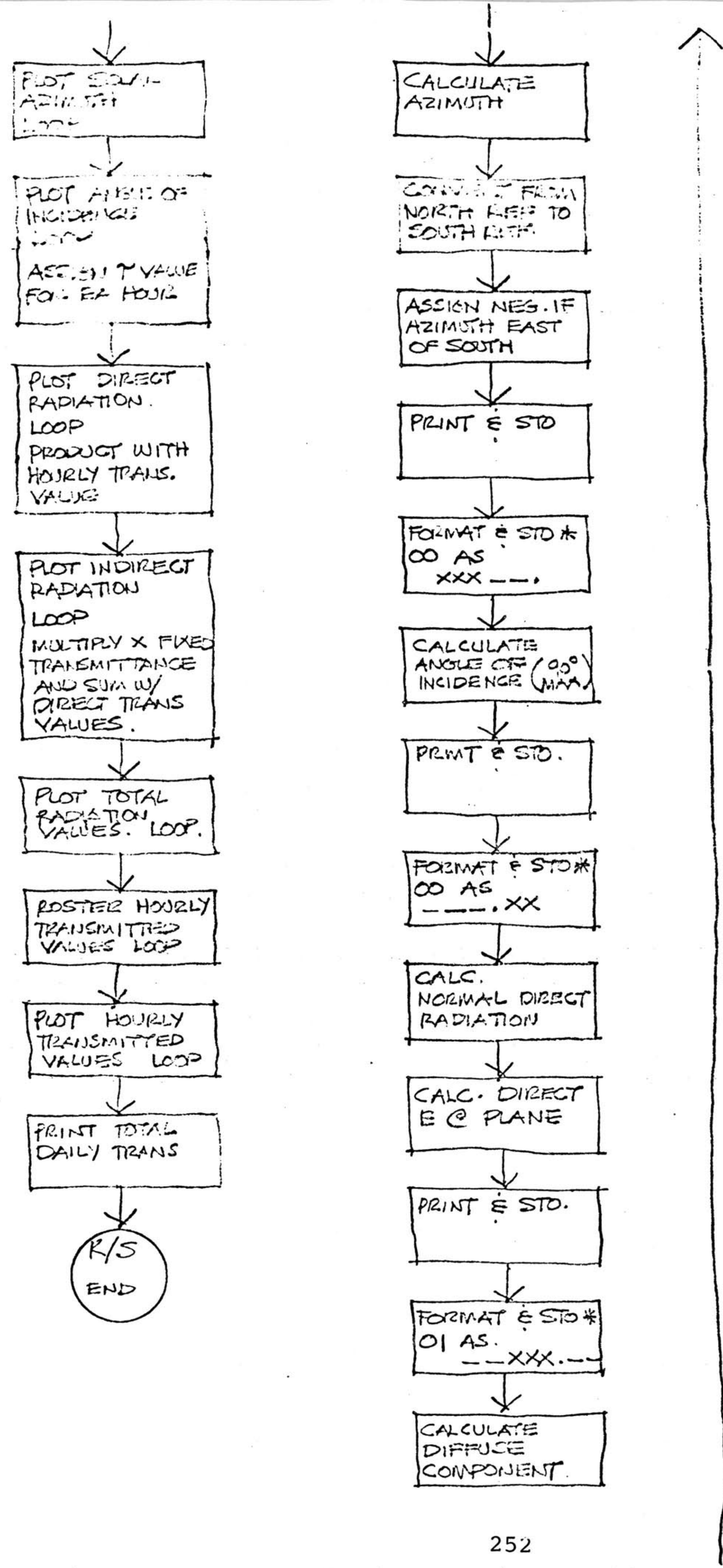
INV x	lnx x	CE x	CLR x	x:t x	x² x
√x x	1/x x	STO x	RCL x	SUM x	yˣ x
EE x	(x	) x	÷ x	GTO x	× x
SBR x	− x	RST x	+ x	R/S	.

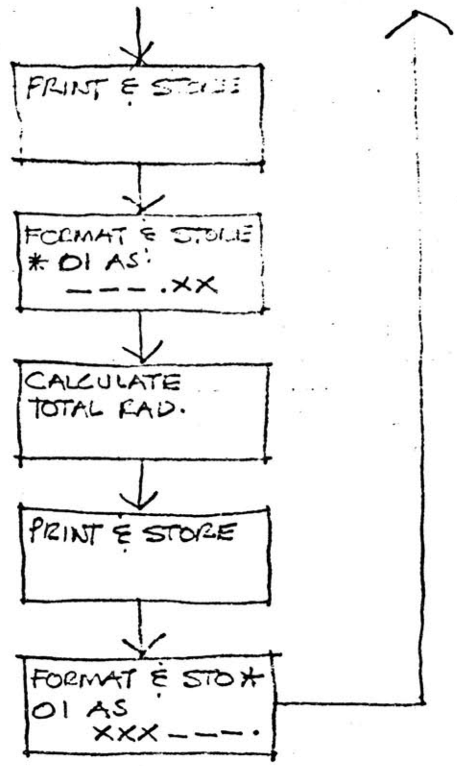
FLAGS 0 1 2 3 4 5 6 7 8 9

DAILY SOLAR PROFILE

FLOW CHART




PLOT SOLAR AZIMUTH LOOP
PLOT ANGLE OF INCIDENCE LOOP
ASSIGN T VALUE FOR EA HOUR
PLOT DIRECT RADIATION. LOOP
PRODUCT WITH HOURLY TRANS. VALUE
PLOT INDIRECT RADIATION
LOOP
MULTIPLY X FIXED TRANSMITTANCE AND SUM W/ DIRECT TRANS VALUES.
PLOT TOTAL RADIATION VALUES. LOOP.
ROSTER HOURLY TRANSMITTED VALUES LOOP
PLOT HOURLY TRANSMITTED VALUES LOOP
PRINT TOTAL DAILY TRANS
R/S
END
CALCULATE AZIMUTH
CONVERT FROM NORTH REF TO SOUTH REF.
ASSIGN NEG. IF AZIMUTH EAST OF SOUTH
PRINT & STO
FORMAT & STO * 00 AS XXX . — —
CALCULATE ANGLE OF INCIDENCE (90° MAX)
PRINT & STO.
FORMAT & STO * 00 AS — — —. XX
CALC. NORMAL DIRECT RADIATION
CALC. DIRECT E @ PLANE
PRINT & STO.
FORMAT & STO * 01 AS. — — XXX. — —
CALCULATE DIFFUSE COMPONENT.


PRINT & STORE
FORMAT & STORE
* 01 AS:
---.XX
CALCULATE
TOTAL RAD.
PRINT & STORE
FORMAT & STO*
01 AS
XXX---.

STORAGE REGISTER ASSIGNMENT

DAILY SOLAR PROFILE

REGISTER NO.	PROGRAM NO 1	PROGRAM NO. 2
0	IND. ADDRESS FOR 30-44	INDIRECT ADDRESS
1	IND. ADDRESS FOR 45-59	DSZ COUNTER
2	LATTITUDE	
3	LONGITUDE	INDIRECT ADDRESS
4	ATMOSPHERIC CLEARANCE	INDIRECT ADDRESS
5	EQ. OF TIME	DSZ COUNTER
6	DECLINATION	ALPHA
7	A FACTOR	TRANS. @ 0°-55° / ALPHA
8	B FACTOR	TRANS @ 55°-65° / ALPHA
9	C FACTOR	TRANS @ 65°-75° / ALPHA
10	GROUND REFLECTION	TRANS @ 75°-90° / ALPHA
11	WALL TILT	ALPHA
12	WALL ORIENTATION	ALPHA
13	LONGITUDE CORRECTION	ALPHA
14	HOUR in MINUTES	ALPHA
15	HOUR ANGLE	ALPHA
16	ALTITUDE	GRAPH MINIMUM
17	AZIMUTH	GRAPH MAXIMUM
18	WALL-SUN ANGLE	GRAPH INCREMENT
19	ANGLE OF INCIDENCE	ALPHA
20	NORMAL ENERGY	ALPHA
21	DIRECT ENERGY @ PLANE	ALPHA
22	F_{sg} GROUND	ALPHA
23	F_{ss} SKY	ALPHA
24	SKY DIFFUSE COMPONENT	ALPHA
25	GROUND DIFFUSE COMPONENT	ALPHA
26	TOTAL DIFFUSE @ PLANE	ALPHA
27	TOTAL RADIATION @ PLANE	DAILY SUM OF TRANS. RAD.
28	DAILY SUM OF INCID. RAD.	
29	HOUR COUNTER	
30-44	STORAGE FOR ALT, AZI, ∠INC.	STORAGE FOR TRANS. VALUES
45-59	STORAGE FOR DIR, IND, & TOT RADIATION	

DAILY PROFILE
LISTING CARD SIDES 1 & 2

000	58	FIX
001	02	02
002	02	2
003	09	9
004	42	STO
005	00	00
006	04	4
007	04	4
008	42	STO
009	01	01
010	00	0
011	42	STO
012	28	28
013	04	4
014	42	STO
015	29	29
016	76	LBL
017	22	INV
018	01	1
019	44	SUM
020	29	29
021	69	OP
022	20	20
023	69	OP
024	21	21
025	02	2
026	00	0
027	32	X:T
028	43	RCL
029	29	29
030	67	EQ
031	71	SBR
032	87	IFF
033	01	01
034	23	LNX
035	98	ADV
036	99	PRT
037	98	ADV
038	76	LBL
039	23	LNX
040	07	7
041	93	.
042	05	5
043	32	X:T
044	53	(
045	53	(
046	43	RCL
047	03	03
048	76	LBL
049	24	CE
050	75	-
051	01	1
052	05	5
053	54	)
054	77	GE
055	24	CE
056	94	+/-
057	65	×
058	04	4
059	54	)
060	42	STO
061	13	13
062	53	(
063	53	(
064	43	RCL
065	29	29
066	75	-
067	01	1
068	02	2
069	54	)
070	65	×
071	06	6
072	00	0
073	54	)
074	42	STO
075	14	14
076	53	(
077	53	(
078	43	RCL
079	13	13
080	85	+
081	43	RCL
082	14	14
083	85	+
084	43	RCL
085	05	05
086	54	)
087	65	×
088	93	.
089	02	2
090	05	5
091	54	)
092	94	+/-
093	42	STO
094	15	15
095	93	.
096	01	1
~~097~~	~~34~~	~~[illegible]~~
098	32	X:T
099	53	(
100	53	(
101	43	RCL
102	02	02
103	39	COS
104	65	×
105	43	RCL
106	06	06
107	39	COS
108	65	×
109	43	RCL
110	15	15
111	39	COS
112	54	)
113	85	+
114	53	(
115	43	RCL
116	02	02
117	38	SIN
118	65	×
119	43	RCL
120	06	06
121	38	SIN
122	54	)
123	54	)
124	22	INV
125	38	SIN
126	42	STO
127	16	16
128	22	INV
129	77	GE
130	22	INV
131	87	IFF
132	01	01
133	25	CLR
134	99	PRT
135	76	LBL
136	25	CLR
137	59	INT
138	72	ST*
139	00	00
140	53	(
141	43	RCL
142	06	06
143	38	SIN
144	65	×
145	43	RCL
146	02	02
147	39	COS
148	54	)
149	75	-
150	53	(
151	43	RCL
152	06	06
153	39	COS
154	65	×
155	43	RCL
156	02	02
157	38	SIN
158	65	×
159	43	RCL
160	15	15
161	39	COS
162	54	)
163	95	=
164	55	÷
165	43	RCL
166	16	16
167	39	COS
168	95	=
169	32	X:T
170	01	1
171	32	X:T
172	22	INV
173	77	GE
174	33	X²
175	01	1
176	76	LBL
177	33	X²
178	22	INV
179	39	COS
180	94	+/-
181	85	+
182	01	1
183	08	8
184	00	0
185	95	=
186	42	STO
187	17	17
188	29	CP
189	43	RCL
190	15	15
191	22	INV
192	77	GE
193	43	RCL
194	01	1
195	94	+/-
196	49	PRD
197	17	17
198	76	LBL
199	43	RCL
200	43	RCL

201	17	17
202	87	IFF
203	01	01
204	42	STO
205	99	PRT
206	76	LBL
207	42	STO
208	94	+/-
209	85	+
210	01	1
211	05	5
212	00	0
213	95	=
214	59	INT
215	65	×
216	01	1
217	00	0
218	00	0
219	95	=
220	74	SM*
221	00	00
222	09	9
223	00	0
224	32	X:T
225	43	RCL
226	17	17
227	85	+
228	43	RCL
229	12	12
230	95	=
231	50	I×I
232	42	STO
233	18	18
234	53	(
235	53	(
236	43	RCL
237	16	16
238	39	COS
239	65	×
240	43	RCL
241	18	18
242	39	COS
243	65	×
244	43	RCL
245	11	11
246	38	SIN
247	54	)
248	85	+
249	53	(
250	43	RCL
251	16	16
252	38	SIN
253	65	×
254	43	RCL
255	11	11
256	39	COS
257	54	)
258	54	)
259	22	INV
260	39	COS
261	22	INV
262	77	GE
263	53	(
264	09	9
265	00	0
266	76	LBL
267	53	(
268	42	STO
269	19	19
270	87	IFF
271	01	01
272	54	)
273	99	PRT
274	76	LBL
275	54	)
276	59	INT
277	55	÷
278	01	1
279	00	0
280	00	0
281	95	=
282	74	SM*
283	00	00
284	53	(
285	53	(
286	53	(
287	43	RCL
288	08	08
289	55	÷
290	43	RCL
291	16	16
292	38	SIN
293	54	)
294	22	INV
295	23	LNX
296	35	1/X
297	65	×
298	43	RCL
299	07	07
300	54	)
301	65	×
302	53	(
303	43	RCL
304	04	04
305	54	)
306	54	)
307	42	STO
308	20	20
309	65	×
310	43	RCL
311	19	19
312	39	COS
313	95	=
314	42	STO
315	21	21
316	87	IFF
317	01	01
318	55	÷
319	99	PRT
320	76	LBL
321	55	÷
322	59	INT
323	72	ST*
324	01	01
325	53	(
326	53	(
327	53	(
328	01	1
329	75	-
330	43	RCL
331	11	11
332	39	COS
333	54	)
334	55	÷
335	02	2
336	54	)
337	42	STO
338	22	22
339	94	+/-
340	85	+
341	01	1
342	54	)
343	42	STO
344	23	23
345	53	(
346	43	RCL
347	09	09
348	65	×
349	43	RCL
350	20	20
351	65	×
352	43	RCL
353	23	23
354	54	)
355	42	STO
356	24	24
357	53	(
358	43	RCL
359	20	20
360	65	×
361	53	(
362	43	RCL
363	09	09
364	85	+
365	43	RCL
366	16	16
367	38	SIN
368	54	)
369	65	×
370	43	RCL
371	10	10
372	65	×
373	43	RCL
374	22	22
375	54	)
376	42	STO
377	25	25
378	85	+
379	43	RCL
380	24	24
381	95	=
382	42	STO
383	26	26
384	87	IFF
385	01	01
386	61	GTO
387	99	PRT
388	76	LBL
389	61	GTO
390	59	INT
391	55	÷
392	01	1
393	00	0
394	00	0
395	95	=
396	74	SM*
397	01	01
398	53	(
399	43	RCL
400	26	26

3.

```
401  85  +
402  43  RCL
403  21  21
404  54  )
405  42  STO
406  27  27
407  87  IFF
408  01  01
409  65  ×
410  99  PRT
411  76  LBL
412  65  ×
413  59  INT
414  44  SUM
415  28  28
416  65  ×
417  01  1
418  00  0
419  00  0
420  00  0
421  95  =
422  74  SM*
423  01  01
424  61  GTO
425  22  INV
426  76  LBL
427  71  SBR
428  98  ADV
429  98  ADV
430  69  OP
431  00  00
432  22  INV
433  58  FIX
434  43  RCL
435  28  28
436  99  PRT
437  98  ADV
438  03  3
439  05  5
440  01  1
441  07  7
442  01  1
443  03  3
444  01  1
445  06  6
446  00  0
447  00  0
448  69  OP
449  01  01
450  00  0
```

```
451  04  4
452  00  0
453  05  5
454  00  0
455  06  6
456  00  0
457  00  0
458  69  OP
459  02  02
460  69  OP
461  05  05
462  98  ADV
463  91  R/S
464  00  0
465  00  0
466  00  0
467  00  0
468  00  0
469  00  0
470  00  0
471  00  0
472  00  0
473  00  0
474  00  0
475  00  0
476  00  0
477  00  0
478  00  0
479  00  0
```

LABELS

```
017  22  INV
039  23  LNX
049  24  CE
136  25  CLR
177  33  X²
199  43  RCL
207  42  STO
267  53  (
275  54  )
321  55  ÷
389  61  GTO
412  65  ×
427  71  SBR
```

DAILY PROFILE
LISTING CARD SIDES 3 & 4

000	69	OP
001	00	00
002	43	RCL
003	23	23
004	69	OP
005	01	01
006	43	RCL
007	24	24
008	69	OP
009	02	02
010	43	RCL
011	25	25
012	69	OP
013	03	03
014	69	OP
015	05	05
016	98	ADV
017	06	6
018	42	STO
019	00	00
020	01	1
021	00	0
022	32	X⇌T
023	76	LBL
024	11	A
025	69	OP
026	00	00
027	43	RCL
028	00	00
029	67	EQ
030	12	B
031	73	RC*
032	00	00
033	69	OP
034	02	02
035	69	OP
036	05	05
037	43	RCL
038	00	00
039	99	PRT
040	91	R/S
041	99	PRT
042	98	ADV
043	72	ST*
044	00	00
045	69	OP
046	20	20
047	61	GTO
048	11	A
049	76	LBL
050	12	B
051	98	ADV
052	98	ADV
053	61	GTO
054	22	INV
055	76	LBL
056	13	C
057	43	RCL
058	06	06
059	61	GTO
060	16	A'
061	76	LBL
062	14	D
063	43	RCL
064	07	07
065	61	GTO
066	16	A'
067	76	LBL
068	15	E
069	43	RCL
070	08	08
071	61	GTO
072	16	A'
073	76	LBL
074	23	LNX
075	69	OP
076	00	00
077	69	OP
078	02	02
079	69	OP
080	05	05
081	92	RTN
082	76	LBL
083	24	CE
084	03	3
085	00	0
086	42	STO
087	00	00
088	01	1
089	05	5
090	42	STO
091	01	01
092	00	0
093	42	STO
094	16	16
095	09	9
096	00	0
097	42	STO
098	17	17
099	04	4
100	93	.
101	05	5
102	42	STO
103	18	18
104	92	RTN
105	76	LBL
106	25	CLR
107	04	4
108	05	5
109	42	STO
110	00	00
111	01	1
112	05	5
113	42	STO
114	01	01
115	92	RTN
116	76	LBL
117	32	X⇌T
118	69	OP
119	00	00
120	43	RCL
121	19	19
122	69	OP
123	04	04
124	43	RCL
125	16	16
126	69	OP
127	06	06
128	43	RCL
129	20	20
130	69	OP
131	04	04
132	43	RCL
133	17	17
134	69	OP
135	06	06
136	43	RCL
137	21	21
138	69	OP
139	04	04
140	43	RCL
141	18	18
142	69	OP
143	06	06
144	76	LBL
145	33	X²
146	43	RCL
147	22	22
148	69	OP
149	01	01
150	69	OP
151	02	02
152	69	OP
153	03	03
154	69	OP
155	04	04
156	69	OP
157	05	05
158	92	RTN
159	76	LBL
160	22	INV
161	71	SBR
162	33	X²
163	43	RCL
164	10	10
165	71	SBR
166	23	LNX
167	71	SBR
168	24	CE
169	71	SBR
170	32	X⇌T
171	76	LBL
172	35	1/X
173	73	RC*
174	00	00
175	59	INT
176	55	÷
177	01	1
178	00	0
179	00	0
180	95	=
181	22	INV
182	59	INT
183	55	÷
184	93	.
185	00	0
186	04	4
187	05	5
188	95	=
189	69	OP
190	07	07
191	69	OP
192	20	20
193	97	DSZ
194	01	01
195	35	1/X
196	71	SBR
197	33	X²
198	43	RCL
199	11	11
200	71	SBR

201	23	LNX	251	00	00	301	06	6	351	71	SBR
202	71	SBR	252	22	INV	302	00	0	352	25	CLR
203	24	CE	253	59	INT	303	42	STO	353	71	SBR
204	01	1	254	65	×	304	17	17	354	32	X:T
205	05	5	255	01	1	305	01	1	355	76	LBL
206	00	0	256	00	0	306	08	8	356	61	GTO
207	42	STO	257	00	0	307	42	STO	357	73	RC*
208	16	16	258	95	=	308	18	18	358	00	00
209	42	STO	259	32	X:T	309	71	SBR	359	22	INV
210	17	17	260	05	5	310	32	X:T	360	59	INT
211	01	1	261	05	5	311	76	LBL	361	65	×
212	05	5	262	77	GE	312	54	)	362	01	1
213	42	STO	263	13	C	313	73	RC*	363	00	0
214	18	18	264	06	6	314	00	00	364	00	0
215	71	SBR	265	05	5	315	59	INT	365	95	=
216	32	X:T	266	77	GE	316	55	÷	366	42	STO
217	76	LBL	267	14	D	317	01	1	367	03	03
218	43	RCL	268	07	7	318	00	0	368	65	×
219	73	RC*	269	05	5	319	00	0	369	43	RCL
220	00	00	270	77	GE	320	00	0	370	07	07
221	55	÷	271	15	E	321	95	=	371	95	=
222	01	1	272	43	RCL	322	22	INV	372	74	SM*
223	00	0	273	09	09	323	59	INT	373	04	04
224	00	0	274	76	LBL	324	65	×	374	43	RCL
225	95	=	275	16	A'	325	01	1	375	03	03
226	59	INT	276	72	ST*	326	00	0	376	55	÷
227	55	÷	277	00	00	327	00	0	377	01	1
228	01	1	278	32	X:T	328	00	0	378	08	8
229	05	5	279	55	÷	329	95	=	379	95	=
230	95	=	280	04	4	330	64	PD*	380	69	OP
231	69	OP	281	93	.	331	03	03	381	07	07
232	07	07	282	05	5	332	55	÷	382	69	OP
233	69	OP	283	01	1	333	01	1	383	20	20
234	20	20	284	95	=	334	08	8	384	69	OP
235	97	DSZ	285	69	OP	335	95	=	385	24	24
236	01	01	286	07	07	336	69	OP	386	97	DSZ
237	43	RCL	287	69	OP	337	07	07	387	01	01
238	71	SBR	288	20	20	338	69	OP	388	61	GTO
239	33	X²	289	97	DSZ	339	20	20	389	71	SBR
240	43	RCL	290	01	01	340	69	OP	390	33	X²
241	12	12	291	52	EE	341	23	23	391	43	RCL
242	71	SBR	292	71	SBR	342	97	DSZ	392	15	15
243	23	LNX	293	33	X²	343	01	01	393	71	SBR
244	71	SBR	294	43	RCL	344	54	)	394	23	LNX
245	24	CE	295	13	13	345	71	SBR	395	71	SBR
246	71	SBR	296	71	SBR	346	33	X²	396	25	CLR
247	32	X:T	297	23	LNX	347	43	RCL	397	71	SBR
248	76	LBL	298	71	SBR	348	14	14	398	32	X:T
249	52	EE	299	25	CLR	349	71	SBR	399	76	LBL
250	73	RC*	300	03	3	350	23	LNX	400	71	SBR

401	73	RC*
402	00	00
403	55	÷
404	01	1
405	00	0
406	00	0
407	00	0
408	95	=
409	59	INT
410	55	÷
411	01	1
412	08	8
413	95	=
414	69	OP
415	07	07
416	69	OP
417	20	20
418	97	DSZ
419	01	01
420	71	SBR
421	71	SBR
422	33	X²
423	43	RCL
424	25	25
425	71	SBR
426	23	LNX
427	71	SBR
428	24	CE
429	76	LBL
430	17	B'
431	73	RC*
432	00	00
433	99	PRT
434	44	SUM
435	27	27
436	69	OP
437	20	20
438	97	DSZ
439	01	01
440	17	B'
441	98	ADV
442	71	SBR
443	33	X²
444	43	RCL
445	25	25
446	71	SBR
447	23	LNX
448	71	SBR
449	24	CE
450	71	SBR

451	32	X⇄T
452	76	LBL
453	18	C'
454	73	RC*
455	00	00
456	55	÷
457	01	1
458	08	8
459	95	=
460	69	OP
461	07	07
462	69	OP
463	20	20
464	97	DSZ
465	01	01
466	18	C'
467	71	SBR
468	33	X²
469	98	ADV
470	43	RCL
471	26	26
472	69	OP
473	04	04
474	43	RCL
475	27	27
476	69	OP
477	06	06
478	91	R/S
479	00	0

LABELS:

024	11	A
050	12	B
054	13	C
062	14	D
068	15	E
074	23	LNX
083	24	CE
106	25	CLR
117	32	X⇄T
145	33	X²
160	22	INV
172	35	1/X
218	43	RCL
249	52	EE
275	16	A'
312	54	)
356	61	GTO
400	71	SBR
430	17	B'
453	18	C'

CARD SIDE 5 DATA

7.	00
0.	01
0.	02
30.	03
30.	04
15.	05
1200606.	06
606200706.	07
706201006.	08
1006201201.	09
13273740.	10
13462440.	11
1300243115.	12
1624350035.	13
2431160035.	14
3732370035.	15
0.	16
0.	17
0.	18
27324300.	19
23242223.	20
51000000.	21
5151515151.	22
1731371735.	23
13421700.	24
3735133136.	25
37161345.	26
0.	27
0.	28
0.	29
26308.9	30
25116.9	31
23924.9	32

SAMPLE PROBLEM & OUTPUT

WEST FACING WALL (VERTICAL) @ 56° NORTH LAT. & 75° LONG. ON MAY 21ST. GROUND REFLECTANCE = 20%, ATMOSPHERIC CLEARANCE = 1. VALUES ARE FOR SOLAR NOON.

INITIAL DATA INPUT ↓

0.	00
0.	01
56.	02
75.	03
1.	04
0.	05
20.	06
350.	07
0.196	08
0.121	09
0.2	10
90.	11
-90.	12

R/S ↓

HOUR	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00
ALT.	8.48	16.47	24.81	33.11	[illegible]	47.61	52.29	54.00	52.29	47.61
AZI.	-113.41	-101.50	-89.35	-76.31	[illegible]	-44.18	-23.43	0.00	23.43	44.18
∠ INCID.	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	75.92	61.98
DIRECT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	66.44	126.12
INDIRECT	8.10	17.70	25.13	31.11	35.84	39.31	41.45	42.17	41.45	39.31
TOTAL	8.10	17.70	25.13	31.11	35.84	39.31	41.45	42.17	107.89	165.43

NOTE! →
IF ∠ INCIDENCE IS GREATER THAN 90°, 90° WILL BE PRINTED.

15.00

40.90
61.50
48.36
172.43
35.84
208.27

16.00

33.11
76.31
35.53
198.96
31.11
230.06

17.00

24.81
89.35
24.81
199.12
25.13
224.25

18.00

16.47
101.50
20.00
164.76
17.70
182.46

19.00

8.48
113.41
24.81
84.16
8.10
92.25

THIS IS TOTAL INCIDENT ENERGY/ DAY IN BTU/SF

$\boxed{1446.}$

READ 345

ENTER AVE TRANS

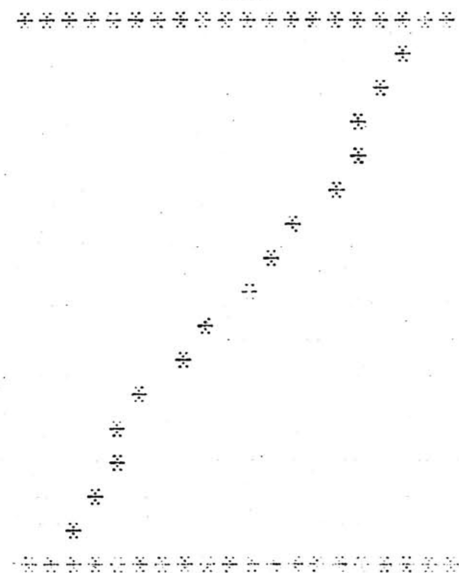
0-55
6.
0.91

55-65
7.
0.83

65-75
8.
0.72

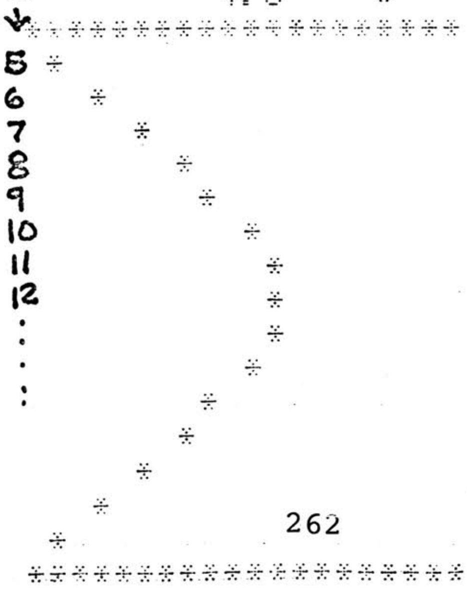
75-90
9.
0.4

AZI.
150. LOW
150. HIGH
15. *

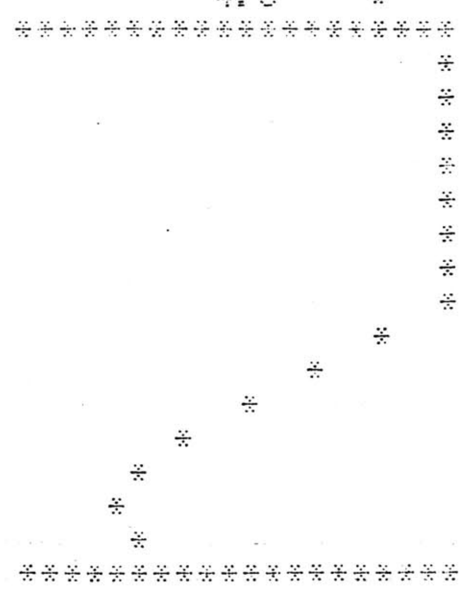


ALT.
0. LOW
90. HIGH
4.5 *

HOUR
5
6
7
8
9
10
11
12
:



A INC
0. LOW
90. HIGH
4.5 *



```
     DIR R
          0.      LOW
        360.      HIGH
         18.      *
********************
*
*
*
*
*
*
*
*
   *
       *
         *
           *
           *
         *
    *
********************
```

```
     TOT R
          0.      LOW
        360.      HIGH
         18.      *
********************
*
*
 *
 *
 *
  *
  *
  *
     *
         *
           *
            *
            *
          *
     *
********************
```

```
********************
     TRANS
          0.      LOW
         90.      HIGH
         4.5      *
********************
*
*
 *
 *
 *
 *
 *
 *
    *
       *
          *
           *
           *
         *
    *
********************
```

```
     IND R
          0.      LOW
        360.      HIGH
         18.      *
********************
*
*
 *
 *
 *
  *
  *
  *
  *
  *
 *
 *
 *
*
*
********************
```

```
     TRANS
          6.64     HOUR 5
         14.11          6
         20.75          7
         25.73          8
         29.05          9
         32.37          .
         34.03          .
         34.86          .
         81.55          .
        136.95
        185.57
        205.91
        201.84
        163.35
         83.08
```

```
1255.79     .TDAY
```

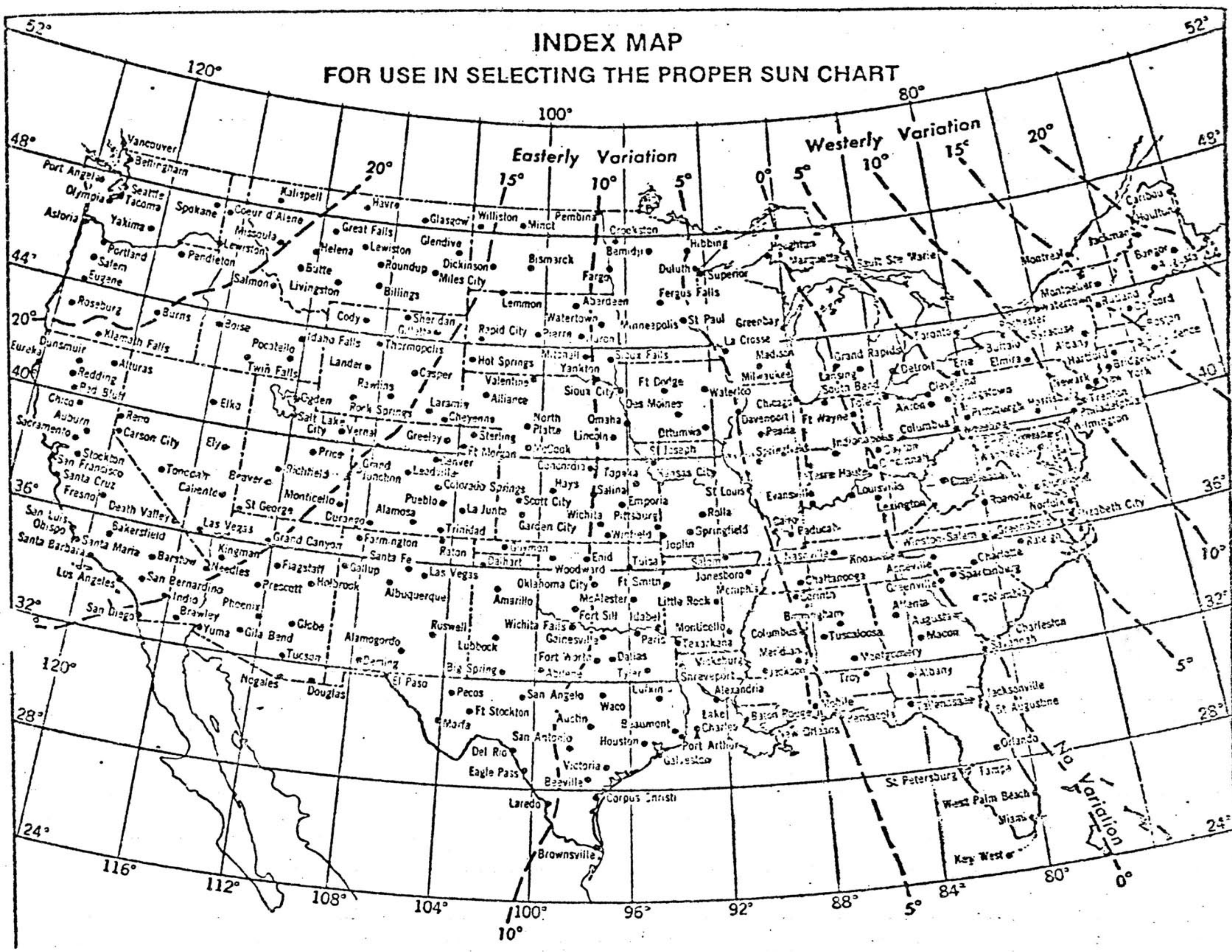
↑

THIS IS TOTAL TRANS. ENERGY PER DAY in BTU/SF

TITLE SOLAR ANGLES & RADIATION PAGE 5 OF 5 **TI Programmable Program Record**

PROGRAMMER BENTON DATE 4 MARCH / 1 MAY 76

Partitioning (Op 17) 479.59 Library Module STD . Printer ______ Cards ______



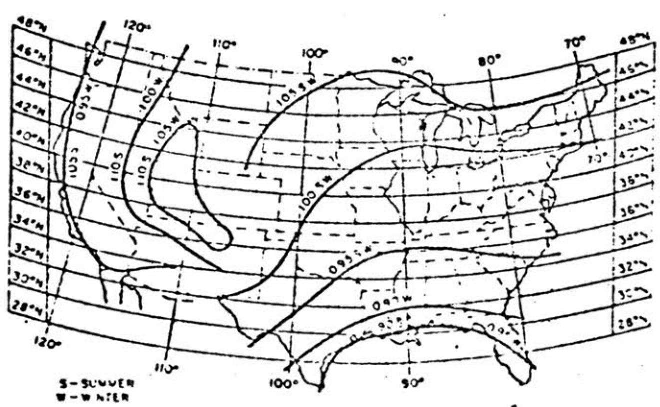
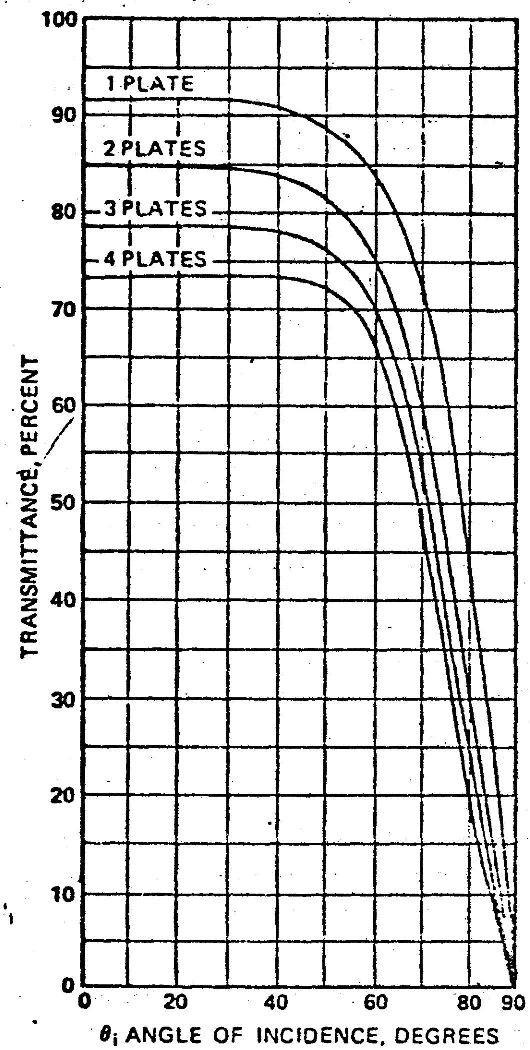


Fig. 4 .... Estimated Atmospheric Clearness Numbers in the U.S. for Nonindustrial Localities

Table 1 .... Solar Radiation Intensity and Related Data Btuh/sq ft

Date	I_0	Equation of Time, min:sec	Declination, deg	A, Btuh/sq ft	B, Air Mass^{-1}	C (Dimensionless)
Jan 21	440.1	−11:18	−20	390	0.142	0.058
Feb 21	436.5	−13:28	−10.8	385	0.144	0.060
Mar 21	430.0	− 7:19	0	376	0.156	0.071
Apr 21	422.8	+ 0:08	+11.6	360	0.180	0.097
May 21	416.5	+ 3:32	+20.0	350	0.196	0.121
June 21	413.1	− 1:48	+23.45	345	0.205	0.134
July 21	413.5	− 6:25	+20.6	344	0.207	0.136
Aug 21	417.6	− 1:18	+12.3	351	0.201	0.122
Sept 21	424.0	+ 7:30	0	365	0.177	0.092
Oct 21	431.1	+15:06	−10.5	378	0.160	0.073
Nov 21	437.6	+13:55	−19.8	387	0.149	0.063
Dec 21	441.0	+ 1:32	−23.45	391	0.142	0.057



The percentage of sunlight transmitted through very clear glass. The angle of incidence is the angle between a ray of sunlight and a line drawn perpendicular to the plates.